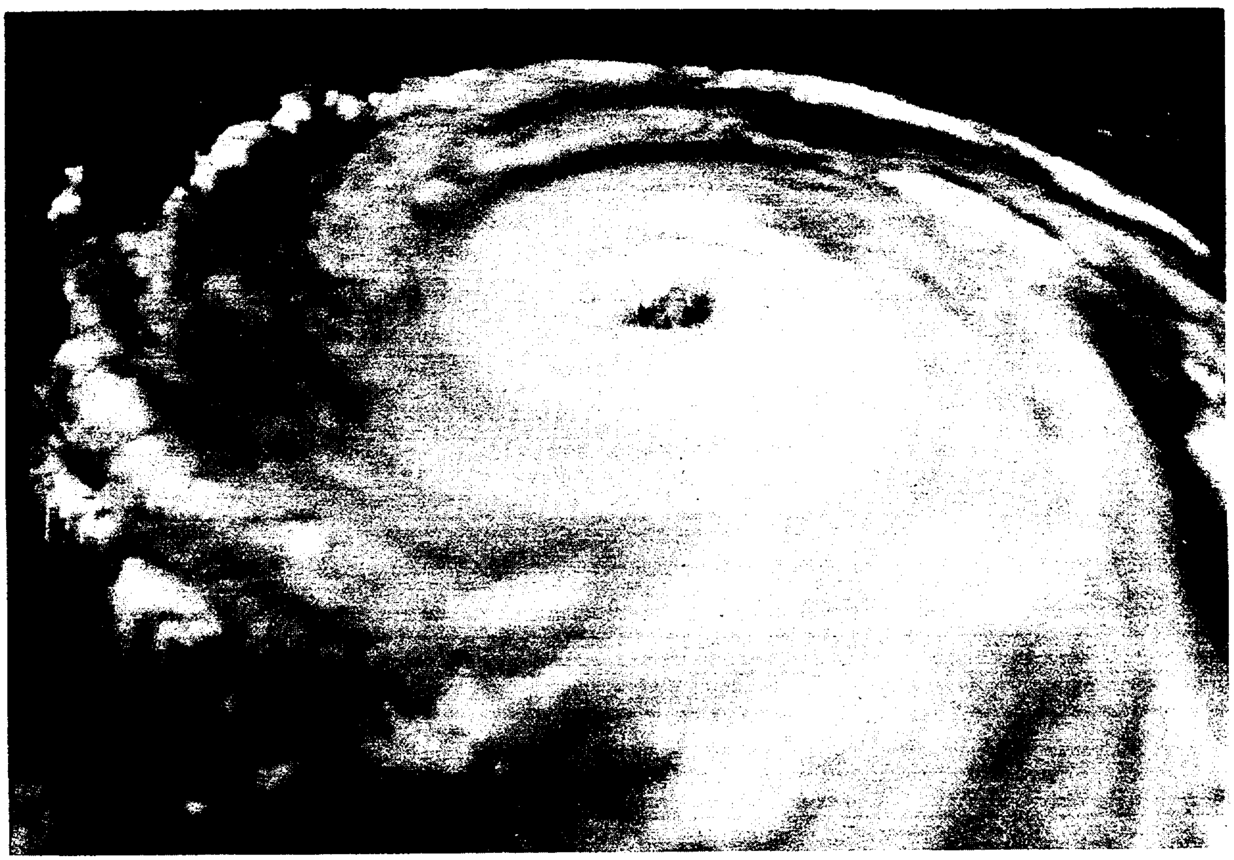
1991 ANNUAL TROPICAL CYCLONE REPORT



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GUAM, MARIANA ISLANDS

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14. ABSTRACT
The mission of the Joint Typhoon Warning Center is multi-faceted and includes: Continuous monitoring of all tropical weather activity in the Northern and Southern Hemispheres, from 180 degrees longitude westward to the east coast of Africa, and the prompt issuance of apropriate advisories and alerts when tropical cyclone development is anticipated.

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FRONT COVER CAPTION: This visual NOAA satellite image of Typhoon Pat (24W) at 070511Z October 1991 is transformed by the Meteorological Imagery, Data Display, and Analysis System (MIDDAS) software into a three-dimensional cloud map by vertically shifting each pixel according to its infrared brightness temperature-derived height. The map is then rotated to produce this dramatic psuedo-perspective.

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FOREWORD

The Annual Tropical Cyclone Report is prepared by the staff of the Joint Typhoon Warning Center (JTWC), a combined Air Force/Navy organization operating under the command of the Commanding Officer, U.S. Naval Oceanography Command Center/Joint Typhoon Warning Center, Guam. The JTWC was founded 1 May 1959 when USCINCPAC directed that a single tropical cyclone warning center be established for the western North Pacific region. The operations of JTWC are guided by CINCPACINST 3140.1U.

The mission of the Joint Typhoon Warning Center is multi-faceted and includes:

1. Continuous monitoring of all tropical weather activity in the Northern and Southern Hemispheres, from 180 degrees east longitude westward to the east coast of Africa, and the prompt issuance of appropriate advisories and alerts when tropical cyclone development is anticipated.

2. Issuance of warnings on all significant tropical cyclones in the above area of responsibility.

3. Determination of requirements for tropical cyclone reconnaissance and assignment of appropriate priorities.

4. Post-storm analysis of significant tropical cyclones occurring within the western North Pacific and North Indian Oceans, which includes an in-depth analysis of tropical cyclones of note and all typhoons.

5. Cooperation with the Naval Research Laboratory (NRL), Monterey, California on the operational evaluation of tropical cyclone models and forecast aids, and the development of new techniques to support operational forecast scenarios.

Changes in this year's publication include: 1) In Chapter 3, extended captions have been used for most western North Pacific tropical depressions and tropical storms to reduce the amount of text; 2) a summary of individual warning statistics (formerly Annex A) has been added as Chapter 6 to provide a printout of 6-hourly positions and verification statistics; 3) the tables in Chapter 6 were expanded to include cross- and along-track errors; 4) the mean errors for each tropical cyclone appear in Chapter 6 instead of Chapter 5 to improve the presentation of error statistics; 5) the cross- and along-track errors prior to 1986 were calculated for the Indian Ocean and western South Pacific to establish a longer term of record; and, 6) western South Pacific verification statistics only include JTWC performance, and do not include NAVWESTOCEANCEN forecasts.

Special thanks to: the men and women at the Fleet Numerical Oceanography Center for their unfaltering operational and software support; the Naval Research Laboratory at Monterey for their dedicated research and forecast improvement initiatives; the Air Force Global Weather Central for continued satellite support and microwave imagery enhancements; the 633 Communications Squadron, Operating Location Charlie and the Operations and Equipment Support departments of the Naval Oceanography Command Center, Guam for their high quality support; personnel of the Pacific Fleet Audio-Visual Center, Guam for their assistance in the reproduction of satellite data for this report; the Navy Publications and Printing Service Branch Office, Guam; Dr. Bob Abbey and the Office of Naval Research for their support to the University of Guam for the Post Doctorate Fellow at JTWC; Dr. Mark Lander for his training efforts, suggestions and valuable insights; and to Sgt. Brian L. McDonald for his continuing excellent support in the JTWC graphics department.

EXECUTIVE SUMMARY

The Joint Typhoon Warning Center, Guam (JTWC) experienced an extremely busy year during 1991, both in terms of the number of tropical cyclone warnings issued and in terms of collateral contingency support. JTWC warnings were critical to the safe deployment of ships and aircraft involved in operations DESERT STORM and DESERT SHIELD, and to the safe and successful employment of ships and aircraft supporting operations SEA ANGEL (Bangladesh relief) and FIERY VIGIL (Philippine evacuation due to the Mount Pinatubo eruption).

In 1990, JTWC set a record for workload by issuing 1139 warnings during the year. That record was short-lived as the Center prepared 1155 warnings in 1991. During the year, the western North Pacific experienced 32 tropical cyclones — 5 super typhoons, 15 less intense typhoons, 10 tropical storms and 2 tropical depressions — which resulted in 835 warnings, not including amendments. North Indian Ocean totals were 56 warnings on 4 tropical cyclones including a rare super cyclone (02B), that killed over 138,000 people in Bangladesh. In the Southern Hemisphere, the Center issued 265 warnings on 22 cyclones. JTWC was in warning status a total of 254 days. One-hundred-ten of those days had at least two storms, 20 days at least 3 storms at the same time, and 4 days had 4 storms occurring simultaneously.

JTWC's track forecast performance for the western North Pacific during 1991 was the best in its 32-year history. Errors were 96 nm at 24 hours, 185 nm at 48 hours, and 287 nm at 72 hours. This represents an improvement of 20, 23, and 20 percent over the long term average errors of 120 nm, 240 nm, and 360 nm. When compared to the climatology-persistence model, CLIPER, JTWC forecasts were 20 percent better across the board. Over 55 percent of the tropical cyclones recurved, making 1991 a relatively difficult forecast year. While JTWC's cross track (directional accuracy) was outstanding, improvement is still needed in forecasting along-track (speed) errors. In the Southern Hemisphere, forecast errors were the lowest in its 11-year history, 115 nm at 24 hours and 220 nm at 48 hours. This is 17 percent below normal.

As in the previous two years, JTWC forecasters out-performed every forecast aid at every forecast period. Routine boguses of tropical cyclone location, intensity, and wind distribution (size) provided to the the Fleet Oceanography Center at 6-hour intervals have significantly improved the performance of the Navy Operational Global Atmospheric Prediction System (NOGAPS), especially in the tropics. As a result, the One-Way (interactive) Tropical Cyclone Model (OTCM) performed well.

Intensity forecast errors for western North Pacific tropical cyclones were 10 percent better than average at 24 and 48 hours, and average at 72 hours. These values were below the 1990 improvements of 22, 19 and 15 percent for the respective periods. In-house techniques developed during 1989 and 1990 to improve intensity forecasts worked well, however the large turnover of experienced personnel and an above average number of midget typhoons proved to be a challenge.

Once again, JTWC has seen many changes over the past year. Perhaps one of the most significant was the operational acceptance by Detachment 1, 633 OSS on 1 April of the Meteorological Imagery, Data Display, and Analysis System (MIDDAS) which continues to improve satellite reconnaissance support to JTWC.

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1. OPERATIONAL PROCEDURES

1.1 GENERAL

The Joint Typhoon Warning Center (JTWC) provides a variety of routine products and services to the organizations within its area of responsibility (AOR), including:

1.1.1 SIGNIFICANT TROPICAL WEATHER ADVISORIES — Issued daily or as needed, to describe all tropical disturbances and their potential for further development during the advisory period.

1.1.2 TROPICAL CYCLONE FORMATION ALERTS — Issued when synoptic or satellite data indicate the development of a tropical cyclone is likely within 24 hours in a specified area.

1.1.3 TROPICAL CYCLONE/ TROPICAL DEPRESSION WARNINGS — Issued periodically throughout each day to provide forecasts of position, intensity, and wind distribution for tropical cyclones in JTWC's AOR.

1.1.4 PROGNOSTIC REASONING MESSAGES — Issued with warnings for tropical depressions, tropical storms, typhoons and super typhoons in the western North Pacific to discuss the rationale for the content of JTWC's warnings.

1.1.5 PRODUCT CHANGES — The contents and availability of the above JTWC products are set forth in USCINCPACINST 3140.1U. Changes to USCINCPACINST 3140.1U and JTWC products and services are proposed and discussed at the Annual Tropical Cyclone Conference.

1.2 DATA SOURCES

1.2.1 COMPUTER PRODUCTS — Numerical and statistical guidance are available from the USN Fleet Numerical Oceanography Center (FNOC) at Monterey, California. These products along with selected ones from the National Meteorological Center (NMC) are received through the Naval Environmental Data Network (NEDN), the Naval Environmental Satellite Network (NESN), and by microcomputer dial-up connections using military and commercial telephone lines. Numerical guidance is also received from Air Force Global Weather Center (AFGWC) at Omaha, Nebraska via the Pacific Digital Information Graphics System (PACDIGS), and from indigenous sources within our AOR.

1.2.2 CONVENTIONAL DATA — These data sets are comprised of land and shipboard surface observations, and enroute meteorological observations from commercial and military aircraft (AIREPS) recorded within six hours of synoptic times, and cloud-motion winds derived from satellite data. The conventional data is hand- and computer-plotted, and hand-analyzed in the tropics for the surface/gradient and 200-mb levels. These analyses are prepared twice daily from 0000Z and 1200Z synoptic data. Also, FNOC supplies JTWC with computer generated analyses and prognoses, from 0000Z and 1200Z synoptic data, at the surface, 850-mb, 700-mb, 500-mb, 400-mb, and 200-mb levels, and deep-layer-mean winds.

1.2.3 SATELLITE RECONNAISSANCE — Meteorological satellite imagery recorded at USAF/USN ground sites and USN ships supply day and night coverage in JTWC's area of responsibility. Interpretation of these satellite

data provides tropical cyclone positions and estimates of current and forecast intensities (Dvorak, 1984). The USAF tactical satellite sites and Air Force Global Weather Central currently receive and analyze special sensor microwave/imager (SSM/I) data to provide estimates of 30-kt (15 m/sec) wind radii near tropical cyclones. Use of satellite reconnaissance is discussed further in section 2.3, Satellite Reconnaissance Summary.

1.2.4 RADAR RECONNAISSANCE — Land-based radar observations are used to position tropical cyclones. Once a well-defined tropical cyclone moves within the range of land-based radar sites, radar reports are invaluable for determination of position and movement. Use of radar reports during 1991 is discussed in section 2.4, Radar Reconnaissance Summary.

1.2.5 AIRCRAFT RECONNAISSANCE — One radar fix was logged for Super Typhoon Walt (04W). In support of the NASA Global Tropospheric Experiment, Pacific Exploratory Measurements -West (GTE/PEM-West), a NASA DC-8 aircraft provided an airborne radar fix of Super Typhoon Mireille (21W).

1.2.6 DRIFTING METEOROLOGICAL BUOYS — In 1989, the Commander, Naval Oceanography Command put the NAVOCEANCOM Integrated Drifting Buoy Plan (1989-1994) into action to meet CINCPACFLT requirements that included tropical cyclone warning support. In 1991, 16 mini-drifting buoys were deployed during the peak period of the WESTPAC tropical cyclone season. P-3 aircraft from Kadena deployed 12 while P-3s assigned to Cubi Point and the Naval Oceanographic Office deployed the remaining 4.

The buoys transmit data to NOAA's TIROS-N polar orbiting satellites, which in turn both store and immediately retransmit the data. If the satellite retransmission can be received on Guam, JTWC acquires the mini-drifting buoy data directly through its Local User Terminal (LUT), and enters the processed buoy data into the AWN under the header SSVE 01 PGTW. Additionally, the stored data aboard the satellites are later recovered via Service ARGOS, processed, and then distributed to operational centers worldwide over the GTS. The National Meteorological Center (NMC) at Suitland, Maryland collects these data from the GTS and enters it into the AWN.

1.2.7 AUTOMATED METEOROLOGICAL OBSERVING STATIONS (AMOS) — Through a cooperative effort between the Naval Oceanography Command, the Department of the Interior, and NOAA (NWS) to increase data available for tropical analysis and forecasting, a network of 20 AMOS stations is being installed in the Micronesian Islands. (Previous to this effort, two sites were installed in the Northern Mariana Islands at Saipan and Rota through a joint venture between the Navy and NOAA/NWS.) JTWC receives data from all AMOS sites via the AWN under the KWBC bulletin headers SMPW01, SIPW01 and SNPW01 (SXMY10 for Saipan and Rota). In September of 1991, the capability to transmit data via System ARGOS and NOAA polar orbiting satellites became available for new AMOS sites, as a backup to regular data transmission via GOES-West. ARGOS upgrades to older existing sites are also being accomplished as the opportunity arises. An AMOS summary appears in Table 1-1.

1.3 COMMUNICATIONS

Primary communications support is provided by the Naval Telecommunications Center (NTCC), Nimitz Hill, a component of the Naval Computers and Telecommunications Area Master Station, Western Pacific (NCTAMS WESTPAC). JTWC uses several

communications systems.

1.3.1 AUTOMATED DIGITAL NETWORK (AUTODIN) — AUTODIN is used for dissemination of warnings, alerts and other related bulletins to Department of Defense (DOD) and other US Government installations. These messages are relayed for further transmission over Navy Fleet Broadcasts, and Coast Guard continuous wave Morse code and voice broadcasts. AUTODIN messages can be relayed to commercial telecommunications for delivery to non-DOD users. Inbound message traffic for JTWC is received via AUTODIN addressed to NAVOCEANCOMCEN GQ//JTWC// or DET 1 633OSS NIMITZ HILL GQ//CC//.

1.3.2 AUTOMATED WEATHER NETWORK (AWN) — The AWN provides weather data over the Pacific Meteorological Data System (PACMEDS). The PACMEDS, operational at JTWC since April 1988, allows Pacific-Theater agencies to receive weather information at 1200 baud. JTWC uses a software package called AWNCOM/WINDS on a microcomputer to send and receive data via the PACMEDS. This system will eventually provide effective storage and manipulation of the large volume of meteorological reports available from throughout JTWC's vast AOR. Through the AWN, JTWC has access to data available on the Global Telecommunications System (GTS). JTWC's AWN station identifier is PGTW.

1.3.3 DEFENSE SWITCHED NETWORK (DSN) — DSN, formerly AUTOVON, is a world-wide general purpose switched telecommunications network for the DOD. The network provides a rapid and vital voice link for JTWC to communicate tropical cyclone information to DOD installations. The DSN telephone numbers for JTWC are 344-4224 or 321-2345.

1.3.4 NAVAL ENVIRONMENTAL DATA NETWORK (NEDN) — The NEDN is the primary link to FNOC to obtain computer generated analyses and prognoses. It is also a backup communication line for requesting and receiving the objective tropical cyclone forecast aids from FNOC's mainframe computers. The

Table 1-1. AUTOMATIC WEATHER OBSERVING STATIONS SUMMARY

Site	Location	Callsign	ID#	Type	System	Installed
Saipan	(15.2°N, 145.7°E)	15D151D2	-----	HANDAR	ARC	1986
Rota	(14.2°N, 145.2°E)	15D16448	-----	HANDAR	ARC	1987
Faraulep*	(8.6°N, 144.6°E)	FARP2	52005	AMOS	C-MAN/ARGOS	1988
Ujae	(8.9°N, 165.8°E)	UJAP2	91365	AMOS	C-MAN	1989
Enewetak	(11.4°N, 162.3°E)	ENIP2	91251	AMOS	C-MAN	1989§
Pagan	(18.1°N, 145.8°E)	PAGP2	91222	AMOS	C-MAN	1990
Kosrae	(5.3°N, 163.0°E)	KOSP2	91356	AMOS	C-MAN	1990§
Mili	(6.1°N, 171.8°E)	MILP2	91377	AMOS	C-MAN	1990
Oroluk	(7.6°N, 155.1°E)	ORKP2	91343	AMOS	C-MAN	1991
Pingelap	(6.3°N, 160.7°E)	PIGP2	91353	AMOS	C-MAN	1991

* Prototype site, which was destroyed 28 November 1990 during STY Owen, will not be reestablished.
§ Sites were upgraded in 1991.

ARC = Automated Remote Collection system (via GOES West)
ARGOS = System ARGOS data collection (via NOAA's TIROS-N spacecraft)
C-MAN = Coastal-Marine Automated Network (via GOES West)

NEDN allows JTWC to communicate directly to the other Naval Oceanography Command Centers around the world.

1.3.5 PUBLIC DATA NETWORK (PDN) — A commercial packet switching network that provides low-speed interactive transmission to users of FNOC products. The PDN is now the primary method for JTWC to request and receive FNOC produced objective tropical cyclone forecast aids. The PDN allows direct access of FNOC products via the Automated Tropical Cyclone Forecast (ATCF) system. The PDN also serves as an alternate method of obtaining FNOC analyses and forecast fields. TYMNET is the contractor providing PDN services to FNOC.

1.3.6 DEFENSE DATA NETWORK (DDN) — The DDN is a DOD computer communications network utilized to exchange data files. Because the DDN has links, or gateways, to non-military information networks, it is frequently used to exchange data with the research community. JTWC's internet address is 26.19.0.250 and E-Mail account is jtops@NOCC.NAVY.MIL. The Det 1, 633 OSS address is JTWCGUAM@KADENA-EMH.AF.MIL.

1.3.7 TELEPHONE FACSIMILE — TELEFAX provides the capability to rapidly scan and transmit, or receive, documents over commercial telephone lines or DSN. TELEFAX is used to disseminate tropical cyclone advisories and warnings to key agencies on Guam and, in special situations, the other Micronesian Islands. Inbound documents for JTWC are received via commercial telephone at (671) 477-6186. If inbound through DSN, the Guam DSN operator 322-1110 can transfer the call to the commercial number 477-6186.

1.3.8 NAVAL ENVIRONMENTAL SATELLITE NETWORK (NESN) — The NESN's primary function is to pass satellite data from the satellite global data base at FNOC to regional centers. Similarly, it can pass satellite data from NOCC/JTWC to FNOC or other regional centers. It also provides a limited back-up for the NEDN.

1.3.9 AIRFIELD FIXED TELECOMMUNICATIONS NETWORK (AFTN) — AFTN was installed at JTWC in January 1990. Though it is primarily for the exchange of aviation information, weather information and warnings are also distributed via this network. It also provides point-to-point communication with other warning agencies. JTWC's AFTN identifier is PGUMYMYT.

1.3.10 LOCAL USER TERMINAL (LUT) — JTWC uses a LUT, provided by the Naval Oceanographic Office, as the primary means of receiving real-time data from drifting meteorological buoys and ARGOS-equipped AMOS via the polar orbiting NOAA satellites.

1.3.11 COMPUTER FACSIMILE — The JTWC Rapid Response Team (RRT) uses a microcomputer to transmit facsimile messages to agencies on Guam and the Northern Marianas when a typhoon threatens the Mariana Islands. The RRT can be reached at (671)-344-7116 or (671)-344-7119.

1.3.12 TELEX — The address for inbound TELEX messages is 197873NOCC GQ.

1.4 DATA DISPLAYS

1.4.1 NAVAL ENVIRONMENTAL DISPLAY STATION (NEDS) — The NEDS receives, processes, stores, displays and prints copies of FNOC environmental products. It drives the fleet facsimile broadcast and can also be used to generate the requests for objective

tropical cyclone forecast techniques.

1.4.2 AUTOMATED TROPICAL CYCLONE FORECAST SYSTEM (ATCF) — The ATCF cuts message preparation time and reduces the number of corrections to JTWC's alerts and warnings. The ATCF automatically computes the myriad of statistics calculated by JTWC. Links have been established through a Local Area Network (LAN) to the NOCC Operations watch team to facilitate the generation of tropical cyclone warning graphics for the fleet facsimile broadcasts and for NOCC's local metwatch program and warning products for Micronesia. A module permits satellite reconnaissance fixes to be input from Det 1, 633 OSS into the LAN. Several other modules are still under development including: direct links to NTCC, the LUT, and AWNCOM/WINDS.

1.4.3 PACIFIC DIGITAL INFORMATION GRAPHICS SYSTEM (PACDIGS) — The PACDIGS is a communications circuit that was expanded to include JTWC in 1988. Air Force Global Weather Central (AFGWC) at Omaha, Nebraska provides a standard set of numerical products to the PACDIGS circuit which can be used for additional evaluation in the development of tropical cyclone warnings.

1.4.4 NAVAL SATELLITE DISPLAY SYSTEM (NSDS) — The NSDS functions as a display of FNOC stored Defense Meteorological Satellite Program (DMSP) imagery and low resolution geostationary imagery. It is the primary means for JTWC to observe areas of cloudiness in the western Indian Ocean.

1.4.5 NAVAL SATELLITE DISPLAY SYSTEM-GEOSTATIONARY(NSDS-G) — The NSDS-G is the backup system used to process high resolution geostationary imagery for tropical cyclone positions and intensity estimates for the western Pacific Ocean. Its built-in sectorizer allows scale expansion and downloading of electronic files to evaluate the data effectively, and monitor several cyclones or suspect areas at once.

1.5 ANALYSES

The JTWC Typhoon Duty Officer (TDO) routinely performs manual streamline analyses of composite surface/gradient-level (3000 ft (914 m)) and upper-tropospheric (centered on the 200-mb level) data for 0000Z and 1200Z each day. Manual sea-level pressure analyses concentrating on the mid-latitudes are available from the NOCC Operations watch team. Computer analyses of the surface, 925-, 850-, 700-, 500-, 400-, and 200-mb levels, deep-layer-mean winds, and frontal boundaries depiction are available from the 0000Z and 1200Z FNOC data bases. Additional sectional charts at intermediate synoptic times and auxiliary charts, such as station-time plot diagrams and pressure-change charts, are analyzed during periods of significant tropical cyclone activity.

1.6 FORECAST PROCEDURES

1.6.1 INITIAL POSITIONING — The warning position is the best estimate of the center of the surface circulation at synoptic time. It is estimated from an analysis of all fix information received from one hour before to one and one-half hours after that synoptic time. The analysis is aided by a computer-generated objective best track scheme that weights fix information based on its statistical accuracy. The TDO includes synoptic observations and other information to adjust the position, testing consistency with the past direction, speed of movement and the influence of the different scales of motions. If the fix data are not available due to reconnaissance platform malfunction or communication problems, or are considered unrepresentative, synoptic data

and/or extrapolation from previous fixes are used.

1.6.2 TRACK FORECASTING — In preparing the JTWC official forecast, the TDO evaluates a wide variety of information, and employs a number of objective and subjective techniques. Because tropical cyclone track forecasting has and continues to require a significant amount of subjective input from the TDO, detailed aspects of the forecast-development process will vary somewhat from TDO to TDO, particularly with respect to the weight given to any of the available guidance. However, throughout 1990, JTWC has developed a standardized, three phase tropical cyclone motion forecasting process to improve not only track forecast accuracy, but also intensity forecast accuracy and forecast-to-forecast consistency.

1.6.2.1 Field Analysis Phase — Navy Operational Global Atmospheric Prediction System (NOGAPS) analyses and prognoses at various levels are evaluated for position, development, and movement of not only the tropical cyclone, but also relevant synoptic features such as: 1) subtropical ridge circulations, 2) mid-latitude short/long-wave troughs and associated weaknesses in the subtropical ridge, 3) monsoon surges, 4) influences of cyclonic cells in the Tropical Upper Tropospheric Trough (TUTT), and 5) other tropical cyclones. This process permits the TDO to develop an initial impression of the environmental steering influences to which the tropical cyclone is and will be subjected to as depicted by NOGAPS. The NOGAPS analyses are then compared to the hand-plotted and analyzed charts prepared by the TDO and to the latest satellite imagery in order to determine how well the NOGAPS-initialization process has conformed to the available synoptic data, and how well the resultant analysis fields agree with the synoptic situation inferred from the imagery. Finally, the TDO compares both the computer and hand-analyzed charts to monthly climatology in order to make a preliminary determination of to what degree the tropical cyclone is and will continue to be (according to NOGAPS) subjected to a climatological or nonclimatological synoptic environment. Noting latitudinal and longitudinal displacements of subtropical ridge and long-wave midlatitude features is of particular importance, and will partially determine the relative weights given to climatologically or dynamically-based objective forecast guidance.

1.6.2.2 Objective Techniques Analysis Phase — After displaying the latest set of forecasts given by JTWC's suite of objective techniques, the TDO then evaluates the pattern produced by the set of forecasts according to the following principles. First, the degree to which the current situation is considered to be and will continue to be climatological is further refined by comparing the forecasts of the climatology-based objective techniques, dynamically-based techniques, and past motion of the present storm. This assessment partially determines the relative weighting given the different classes of objective techniques. Second, the spread of the pattern determined by the set of objective forecasts is used to provide a measure of the predictability of subsequent motion, and the advisability of including a low or moderate probability alternate forecast scenario in the prognostic reasoning message or warning (outside the western North Pacific). The spread of the objective techniques pattern is typically small well-before or well-after recurvature (providing high forecast confidence) and large near recurvature or during a quasi-stationary or erratic movement phase (increasing the likelihood of alternate scenarios).

1.6.2.3 Construct Forecast Phase — The TDO then constructs the JTWC official forecast giving due consideration to the: 1) extent to

which the synoptic situation is and is expected to remain climatological, 2) past statistical performance of the various objective techniques on the current storm, and 3) known properties of individual objective techniques given the present synoptic situation. The following guidance for weighting the objective techniques is applied:

a) Weight persistence strongly in the first 12 to 24 hours of the forecast period.

b) Give significant weight to the last JTWC forecast at all forecast times, unless there is significant evidence to warrant a departure. (Also utilize latest forecasts from regional warning centers, if applicable.)

c) Give more weight to the techniques that have been performing well on the current tropical cyclone and/or are expected to perform well in the current and expected synoptic situation.

d) Stay within the "envelope" determined by the spread of objective techniques forecasts unless there is a specific reason for not doing so (eg., all objective forecasts start out at a significant angle relative to past motion of the current tropical cyclone).

1.6.3 INTENSITY FORECASTING — The empirically derived Dvorak (1984) technique is used as a first guess for the intensity forecast. The TDO then adjusts the forecast after evaluating climatology and the synoptic situation. An interactive conditional climatology scheme allows the TDO to define a situation similar to the system being forecast in terms of location, time of year, current intensity, and intensity trend. Synoptic influences such as the location of major troughs and ridges, and the position and intensity of the TUTT all play a large part in intensifying or weakening a tropical cyclone. JTWC incorporates a checklist into the intensity forecast procedure. Such criteria as upper-level outflow patterns, neutral points, sea-surface temperatures, enhanced monsoonal or cross-equatorial flow, and vertical wind shear are evaluated for their tendency to enhance or inhibit normal development, and are incorporated into the intensity forecast process through locally developed thumb rules. In addition to climatology and synoptic influences, the first guess is modified for interactions with land, with other tropical cyclones, and with extratropical features. Digital pixel information from meteorological satellite data is used to help assess the potential for development, rapid intensification, and time of peak intensity. Climatological and statistical methods are also used to assess the potential for rapid intensification (Mundell, 1990).

1.6.4 WIND-RADII FORECASTING — After the loss of dedicated aircraft reconnaissance, JTWC began over-estimating the extent of damaging winds by as much as 100%. Det 1 Techniques Development incorporated techniques from various sources, leading to development of the Martin-Holland wind radii technique. Wei and Gray, in an unpublished study, showed that cloud shield size related to the extent of damaging winds - tropical cyclones with large cloud shields generally had damaging winds much further from the center than tropical cyclones with small cloud shields. Holland (1980) described an analytic model of tropical cyclone wind profiles which could estimate extent of damaging wind. Holland's equation uses a logarithmic wind profile outside the radius of maximum winds. It is based on size and shape parameters. The size parameter uses the cloud shield size (based on the size of the minus 65°C isotherm outside the central convection) to determine the areal extent of damaging winds. The model uses the Dvorak current intensity estimate to determine the shape parameter. Asymmetry is added based on projected changes in the system's motion and latitude.

1.6.5 EXTRATROPICAL TRANSITION — When a tropical cyclone is forecast to become an extratropical system, JTWC coordinates the transfer of warning responsibility with the appropriate Naval Oceanography Command Regional Center, which assumes warning responsibilities for the extratropical system.

1.6.6 TRANSFER OF WARNING RESPONSIBILITIES — JTWC coordinates the transfer of tropical warning responsibility for tropical cyclones entering or exiting its AOR. For tropical cyclones crossing 180° east longitude in the North Pacific Ocean, JTWC coordinates with the Central Pacific Hurricane Center (CPHC), Honolulu via the Naval Western Oceanography Center (NWOC), Pearl Harbor, Hawaii. For the South Pacific Ocean, JTWC coordinates with the NWOC.

In the event JTWC should become incapacitated, the Alternate Joint Typhoon Warning Center (AJTWC), collocated with NWOC assumes JTWC's functions. Assistance in determining satellite reconnaissance requirements, and in obtaining the resultant data, is provided by the weather unit supporting the 15th Air Base Wing, Hickam AFB, Hawaii.

1.7 WARNINGS

JTWC issues two types of warnings: Tropical Cyclone Warnings and Tropical Depression Warnings.

1.7.1 TROPICAL CYCLONE WARNINGS — These are issued when a closed circulation is evident and maximum sustained winds are forecast to reach 34 kt (18 m/sec) within 48 hours, or when the tropical cyclone is in such a position that life or property may be endangered within 72 hours.

Each Tropical Cyclone Warning is numbered sequentially and includes the following information: the current position of the surface center; an estimate of the position accuracy and the supporting reconnaissance (fix) platform(s); the direction and speed of movement during the past six hours (past 12 hours in the Southern Hemisphere); and the intensity and radial extent of over 30-, 50-, and 100-kt (15-, 26-, and 51 m/sec) surface winds, when applicable. At forecast intervals of 12, 24, 48, and 72 hours (12, 24, and 48 hours in the Southern Hemisphere), information on the tropical cyclone's anticipated position, intensity and wind radii is provided. Vectors indicating the mean direction and mean speed between forecast positions are included in all warnings. In addition, a 3-hour extrapolated position is provided in the remarks section.

Warnings in the western North Pacific and North Indian Oceans are issued every six hours valid at standard times: 0000Z, 0600Z, 1200Z and 1800Z (every 12 hours: 0000Z, 1200Z or 0600Z, 1800Z in the Southern Hemisphere). All warnings are released to the communications network no earlier than synoptic time and no later than synoptic time plus two and one-half hours, so that recipients are assured of having all warnings in hand by synoptic time plus three hours (0300Z, 0900Z, 1500Z and 2100Z). By area, the warning bulletin headers are: WTIO31-35 PGTW for northern latitudes from 35° to 100° east longitude, WTPN31-36 PGTW for northern latitudes from 100° to 180° east longitude, WTXS31-36 PGTW for southern latitudes from 35° to 135° east longitude, and WTPS31-35 PGTW for southern latitudes from 135° to 180° east longitude.

1.7.2 TROPICAL DEPRESSION WARNINGS — These are issued only for western North Pacific tropical depressions that are not expected to reach the criteria for Tropical Cyclone Warnings, as mentioned above. The depression warning contains the same information as a Tropical Cyclone Warning except that the Tropical Depression Warning is issued every 12 hours at standard

synoptic times and extends only to the 36-hour forecast period.

Both Tropical Cyclone and Tropical Depression Warning forecast positions are later verified against the corresponding best track positions (obtained during detailed post-storm analyses) to determine the most probable path and intensity of the cyclone. A summary of the verification results for 1991 is presented in Chapter 5, Summary of Forecast Verification.

1.8 PROGNOSTIC REASONING MESSAGES

These plain language messages provide meteorologists with the rationale for the forecasts for tropical cyclones in the western North Pacific Ocean. They also discuss alternate forecast scenarios. Prognostic reasoning messages (WDPN31-36 PGTW) are prepared to complement tropical cyclone (but not tropical depression) warnings. In addition to these messages, prognostic reasoning information is provided in the remarks section of warnings when significant forecast changes are made or when deemed appropriate by the TDO.

1.9 TROPICAL CYCLONE FORMATION ALERTS

Tropical Cyclone Formation Alerts are issued whenever interpretation of satellite imagery and other meteorological data indicates that the formation of a significant tropical cyclone is likely. These alerts will specify a valid period not to exceed 24 hours and must either be canceled, reissued, or superseded by a warning prior to expiration. By area, the alert bulletin headers are: WTIO21-25 PGTW for northern latitudes from 35° to 100° east longitude, WTPN21-26 PGTW for northern latitudes from 100° to 180° east longitude, WTXS21-26 PGTW for southern latitudes from 35° to 135° east longitude, and WTPS21-25 PGTW for southern latitudes from 135° to 180° east longitude.

1.10 SIGNIFICANT TROPICAL WEATHER ADVISORIES

This product contains a description of all tropical disturbances in JTWC's AOR and their potential for further (tropical cyclone) development. In addition, all tropical cyclones in warning status are briefly discussed.

Two separate messages are issued daily, and each is valid for a 24-hour period. The Significant Tropical Weather Advisory for the Western Pacific Ocean is issued by 0600Z. The Significant Tropical Weather Advisory for the Indian Ocean is issued by 1800Z. These are reissued whenever the situation warrants. For each suspect area, the words "poor", "fair", or "good" are used to describe the potential for development. "Poor" will be used to describe a tropical disturbance in which the meteorological conditions are currently unfavorable for development. "Fair" will be used to describe a tropical disturbance in which the meteorological conditions are favorable for development, but significant development has not commenced or is not expected to occur in the next 24 hours. "Good" will be used to describe the potential for development of a disturbance covered by an alert. By area, the advisory bulletin headers are: ABPW10 PGTW for northern latitudes from 100° to 180° east longitude and southern

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2. RECONNAISSANCE AND FIXES

2.1 GENERAL

The Joint Typhoon Warning Center depends on reconnaissance to provide necessary, accurate, and timely meteorological information in support of advisories, alerts and warnings. JTWC relies primarily on two reconnaissance platforms: satellite and radar. In data rich areas, synoptic data are also used to supplement the above. As in past years, the optimal use of all available reconnaissance resources to support JTWC's products remains a primary concern. Weighing the specific capabilities and limitations of each reconnaissance platform, and the tropical cyclone's threat to life and property both afloat and ashore, continue to be important factors in careful product preparation.

2.2 RECONNAISSANCE AVAILABILITY

2.2.1 SATELLITE — Fixes from Air Force/Navy ground sites and Navy ships provide day and night coverage in JTWC's area of responsibility. Interpretation of this satellite imagery yields tropical cyclone positions and estimates of current and forecast intensities through the Dvorak technique. The Special Sensor Microwave/Imager (SSM/I) data are used to determine the extent of the 30-kt (15 m/sec) winds around the tropical cyclone and to aid in tropical cyclone positioning.

2.2.2 RADAR — Land-based radar remotely senses and maps precipitation within tropical cyclones in the proximity (usually within 175 nm (325 km) of radar sites) of the Philippine Islands, Taiwan, Hong Kong, China, Japan, South Korea, Kwajalein, Guam, Thailand, Australia, and India.

2.2.3 SYNOPTIC — JTWC also determines tropical cyclone positions based on the analysis of surface/gradient-level synoptic data. These positions are an important supplement to fixes provided by remote sensing platforms and become invaluable in situations where neither satellite nor radar fixes are available.

2.3 SATELLITE RECONNAISSANCE SUMMARY

The Air Force provides satellite reconnaissance support to JTWC through the DMSP Tropical Cyclone Reporting Network (DMSP Network), which consists of tactical sites and a centralized facility. The personnel of Det 1, 633 OSS (hereafter referred to as Det 1), collocated with JTWC at Nimitz Hill, Guam, coordinate required tropical cyclone reconnaissance support with the following units:

15 ABW/WE, Hickam AFB, Hawaii
18 OSS/WE, Kadena AB, Okinawa, Japan
603 ACCS/WE, Osan AB, Republic of Korea
Air Force Global Weather Central,
Offutt AFB, Nebraska

Detachment 5, 20 WS, Clark AB, Republic of the Philippines ceased operations in late September following the eruption of Mount Pinatubo and the subsequent closure of Clark AB. These sites provide a combined coverage that includes most of the western North Pacific, from near the international date line westward to the Malay Peninsula. The Naval Oceanography Command Detachment, Diego Garcia, furnishes interpretation of low resolution NOAA polar orbiting coverage in the central Indian Ocean, and Navy ships equipped for direct satellite readout contribute supplementary support. Also, civilian contractors with the U.S. Army at Kwajalein Atoll provide satellite fixes on tropical cyclones

in the Marshall Islands to supplement Det 1's satellite coverage. Additionally, DMSP low resolution satellite mosaics are available from the FNOC via the NEDN and NESN lines. These mosaics are used to metwatch the areas not included in the area covered by the DMSP tactical sites, and provide JTWC forecasters with the capability to "see" what AFGWC's satellite image analysts are fixing, albeit, several hours later.

In addition to polar orbiter imagery, Det 1 uses high resolution geostationary imagery to support the reconnaissance mission. Animation of these geostationary images is invaluable for determining the location of cloud system centers and their motion, particularly in the formative stages. Animation is also valuable in assessing environmental, or ambient, changes affecting tropical cyclone behavior. Det 1 is able to receive and process high resolution digital geostationary data through its Meteorological Imagery, Data Display and Analysis System (MIDDAS), and via the NSDS-G or Navy's Geostationary Satellite Receiving System (GSRS). Phase 1 of MIDDAS, installed in December 1990, consists of a minicomputer and large screen work station which provides advanced graphic and enhancement capabilities for geostationary data. Phase 2, installed in September 1991, increased the system to 3 minicomputers and ingests NOAA High Resolution Picture Transmission (HRPT) and TIROS Operational Vertical Sounder (TOVS) data. Software installed in March 1992 gave MIDDAS the capability to process DMSP imagery. Thus, Det 1 can daily process imagery from at least four polar orbiting and one geostationary spacecraft.

AFGWC is the centralized member of the DMSP network. In support of JTWC, AFGWC processes stored imagery from DMSP and NOAA spacecraft. Stored imagery is recorded on board the spacecraft as they orbit the earth, and is later relayed to AFGWC via a network of command readout sites and communication satellites. This enables AFGWC to obtain the coverage necessary to fix all tropical cyclones within JTWC's AOR. AFGWC has the primary responsibility to provide tropical cyclone reconnaissance over the entire Indian Ocean, southwest Pacific, and the area near 180° east longitude in the western North Pacific Ocean. As a backup, AFGWC can be tasked to provide tropical cyclone reconnaissance support in the western North Pacific, when DMSP tactical site coverage is impaired or lost.

The hub of the DMSP network is Det 1. Based on available satellite coverage, Det 1 is responsible for coordinating satellite reconnaissance requirements with JTWC and tasking the individual network sites for the necessary tropical cyclone fixes, current intensity estimates, forecast intensities, and SSM/I surface wind information. When a particular satellite pass is selected to support the development of JTWC's next tropical cyclone warning, two sites are tasked to fix the tropical cyclone from the same pass. This "dual-site" concept provides the necessary redundancy that virtually guarantees JTWC a satellite fix to support each warning. It also supplies independent assessments of the same data to provide JTWC forecasters a measure of confidence in the location and intensity information.

The network provides JTWC with several products and services. The main service is to monitor the AOR for indications of tropical cyclone development. If development is suspected, JTWC is notified. Once JTWC

TABLE 2-1 **POSITION CODE NUMBERS (PCN)**

PCN	METHOD FOR CENTER DETERMINATION/GRIDDING
1	EYE/GEOGRAPHY
2	EYE/EPHEMERIS
3	WELL DEFINED CIRCULATION CENTER/GEOGRAPHY
4	WELL DEFINED CIRCULATION CENTER/EPHEMERIS
5	POORLY DEFINED CIRCULATION CENTER/GEOGRAPHY
6	POORLY DEFINED CIRCULATION CENTER/EPHEMERIS

issues either a Tropical Cyclone Formation Alert or a warning, the network provides three products: tropical cyclone positions, current intensity estimates and forecast intensities. Each satellite-derived tropical cyclone position is assigned a Position Code Number (PCN), which is a measure of positioning confidence. The PCN is determined by a combination of the availability of visible landmarks in the image that can be used as references for precise gridding and the degree of organization of the tropical cyclone's cloud system (Table 2-1). Once the tropical cyclone reaches 50 kt (25 m/sec), information on the distribution of 30-kt (15-m/sec) winds is provided using SSM/I data.

Det 1 provides a minimum of one estimate of the tropical cyclone's current intensity every 6 hours once JTWC is in alert or warning status. Current intensity estimates and 24-hour intensity forecasts are made using the Dvorak (1975, 1984) technique for both visual and enhanced infrared imagery (Figure 2-1). The enhanced infrared technique is preferred due to its increased objectivity and accuracy, however, the visual technique is used to supplement this information during the daylight hours. The standard relationship between tropical cyclone "T-number", maximum sustained surface wind speed and minimum sea-level pressure (Atkinson and Holliday, 1977) for the Pacific is shown in Table 2-2. For subtropical cyclones, intensity estimates are made using the Hebert and Poteat (1975) technique.

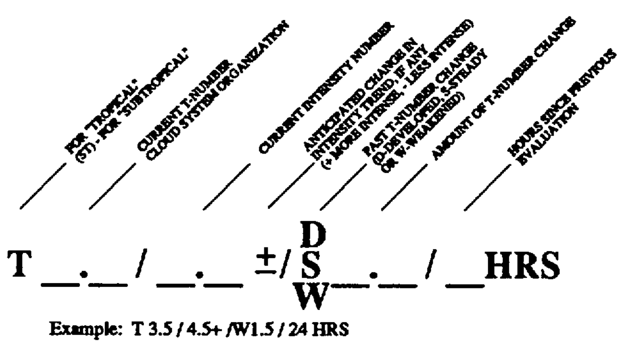

Figure 2-1. Dvorak code for communicating estimates of current and forecast intensity derived from satellite data. In the example, the current "T-number" is 3.5, but the current intensity is 4.5. The cloud system has weakened by 1.5 "T-numbers" since the previous evaluation conducted 24-hours earlier. The plus (+) symbol indicates an expected reversal of the weakening trend or very little further weakening of the tropical cyclone during the next 24-hour period.

2.3.1 SATELLITE PLATFORM SUMMARY — Figure 2-2 shows the status of operational polar orbiting spacecraft. Four DMSP spacecraft, 19543 (F8), 20542 (F9), 21544 (F10), and 22546 (F11) were operational during 1991. The F8's SSM/I lost its horizontally polarized 85 gigahertz channel early in the year, however, the channel started providing limited, but useful, data again in October. The spacecraft's Operational Line Scan (OLS) sensor failed on 16 August. The F9 was operational throughout 1991, but lost its OLS on 21 February 1992. The F10, although launched into an elliptical orbit, became operational 15 January 1991. The platform's fluctuating altitudes caused persistent gridding problems, and it continues to precess about 50 seconds a week, thus it is no longer in a sun synchronous orbit. F11 was launched 28 November and became operational on 17 December; one of the shortest periods between launch and operational acceptance in the DMSP history. Two SSM/I sensors, mounted on the F8 and F10 DMSP spacecraft, were operational throughout 1991. A third sensor, recently

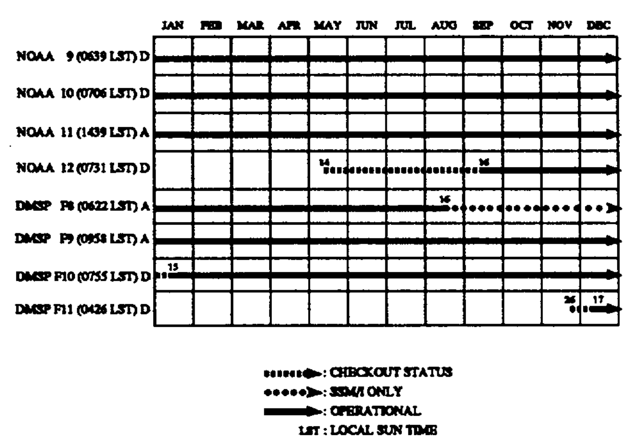

Figure 2-2. Polar orbiters for 1991.

launched on the F11, will expand SSM/I coverage during 1992. Although the horizontally polarized 85 gigahertz channel failed on the F8, the sensor continued to provide valuable surface wind data, and positioning data could be derived using the differential of the 37 gigahertz vertically and horizontally polarized data. With regard to NOAA spacecraft, NOAA 9 remained in standby, and NOAA 10 and NOAA 11 were operational throughout 1991. NOAA 12 was launched 14 May and became operational on 16 September.

2.3.2 STATISTICAL SUMMARY — During 1991, information from the DMSP network was the primary input to JTWC for operational warnings and post analysis best tracks in the entire 53-million square mile area of responsibility for the warning center. Almost all the warnings were based on satellite reconnaissance. JTWC received a total of 4746 satellite fixes during the year. Of these, 3139 were for the western North Pacific, 139 for the North Indian Ocean and 1468 for the Southern Hemisphere. Of this, 38 percent were from polar orbiter, and 62 percent were from geostationary platforms. These totals include 128 fixes in the western North Pacific, 14 in the North Indian Ocean, and 196 in the Southern Hemisphere from non-network sources. The increase in percentage of geostationary fixes (only 49 percent in 1990) is attributed to the deactivation of the DMSP site at Clark AB, significant operational down-time at network sites, and the expanded capability of the MIDDAS. During July through November, significant outage hours for the network sites rose to 51 percent, compared with 12.3 percent for the same period in 1990. A comparison of satellite fixes from all data sources with their corresponding best track positions is shown in Table 2-3.

2.3.3 NEW TECHNIQUES — The MIDDAS system has and will continue to expand Det 1's capabilities to analyze tropical cyclones. In addition to providing analysts with the capability to rapidly make or modify satellite

TABLE 2-2

MAXIMUM SUSTAINED WIND SPEED (KT) AS A FUNCTION OF DVORAK CURRENT AND FORECAST INTENSITY NUMBER AND MINIMUM SEA-LEVEL PRESSURE (MSLP)

TROPICAL CYCLONE INTENSITY NUMBER	WIND SPEED	MSLP (NW PACIFIC)
0.0	<25	- - - -
0.5	25	- - - -
1.0	25	- - - -
1.5	25	- - - -
2.0	30	1000
2.5	35	997
3.0	45	991
3.5	55	984
4.0	65	976
4.5	77	966
5.0	90	954
5.5	102	941
6.0	115	927
6.5	127	914
7.0	140	898
7.5	155	879
8.0	170	858

image enhancements, post analysis techniques are more flexible than previous years. Animated loops and sectorized images archived on 4 mm, 1.2 gigabyte Digital Audio Tapes are rapidly replacing hard copy imagery. When the data files are reloaded on the system from tape, they can again be used for detailed analysis.

The Techniques Development section is working on objective methods to complement current analyses. Constructing satellite derived time series of the area of tropical cyclone deep convection that is colder than a given threshold temperature allows graphical representation of convective trends. Interpretation of the trends are expected to improve genesis analysis, forecasts of rapid intensification, and forecasts of peaking day. (Refer to Chapter 7.)

Tactical sites in the Pacific on the islands of Guam, Oahu, Luzon and Okinawa, as well as AFGWC, received the Mission Sensor Tactical Imaging Computer (MISTIC) during the summer of 1990. Osan AB obtained the former Clark AB MISTIC system in early 1992. The AFGWC Tropical Section continues to provide the majority of the SSM/I support to JTWC. On 1 November 1991, AFGWC began testing 12-bit, high resolution SSM/I data on their Satellite Data Handling System. Initial results have been very encouraging and the final operational acceptance occurred on 1 March 92. AFGWC, Det 1, and 18 OSS/WE provided bulletins to JTWC describing the extent of 30-kt (15 m/sec) winds surrounding the tropical cyclone for all systems with maximum sustained winds of 50 kt (25 m/sec) or greater. In the summer of 1992, expanded MISTIC software should be delivered to the tactical sites. This software will allow processing of full-resolution 12-bit SSM/I data, and will co-register OLS imagery and the SSM/I data.

TABLE 2-3

MEAN DEVIATION (NM) OF ALL SATELLITE DERIVED TROPICAL CYCLONE POSITIONS FROM JTWC BEST TRACK POSITION (NUMBER OF CASES IN PARENTHESES)

PCN	1981-1990 AVERAGE		1991 AVERAGE	
NORTHWEST PACIFIC OCEAN				
1&2	13.6	(4442)	13.2	(858)
3&4	20.6	(5112)	22.6	(574)
5&6	35.5	(11040)	40.2	(1707)
Totals:	**27.1**	**(20594)**	**29.6**	**(3139)**
NORTH INDIAN OCEAN				
1&2	13.3	(120)	16.7	(25)
3&4	29.6	(89)	26.6	(6)
5&6	38.4	(905)	47.3	(108)
Totals:	**35.0**	**(1114)**	**40.9**	**(139)**
WESTERN SOUTH PACIFIC AND SOUTH INDIAN OCEAN				
1&2	16.3	(1330)	16.1	(226)
3&4	26.9	(1048)	27.1	(251)
5&6	36.0	(6284)	35.0	(991)
Totals:	**31.9**	**(8662)**	**30.7**	**(1468)**

2.3.4 FUTURE OF SATELLITE RECONNAISSANCE — MIDDAS was formally accepted for operational use by Det 1 on 1 April 1992, and it will provide JTWC with enhanced satellite support for 1992. At Det 1, the goal is to have a fully integrated satellite system, capable of ingesting data from both geostationary and polar satellites and then overlaying graphics from and interfacing with multiple data sources, e.g., Automated Weather Distribution System (AWDS), NEXRAD Doppler radar, and the Mark IVB meteorological data station. The Mark IVB is scheduled to replace the Mark III and Mark IV satellite ingest and display systems during the 1994 time-frame.

Until the installation of AWDS in 1994, the plan is to retrieve the conventional data via the Automated Weather Network (AWN) and overlay it on the satellite imagery. Software developed for the MIDDAS is able to overlay wind, temperature, pressure and height fields on the satellite imagery. Det 1 and JTWC will

have the capability to integrate large volumes of data more efficiently and effectively than ever before.

2.4 RADAR RECONNAISSANCE SUMMARY

Twenty-two of the thirty-two significant tropical cyclones in the western North Pacific during 1991 passed within range of land-based radar with sufficient cloud pattern organization to be fixed. A total of 994 land-based radar fixes were obtained and logged at JTWC. There were two airborne radar fixes.

The WMO radar code defines three categories of accuracy: good (within 10 km (5 nm)), fair (within 10-30 km (5-16 nm)), and poor (within 30-50 km (16-27 nm)). Of the 1088 radar fixes encoded in this manner; 313 were good, 331 were fair, and 444 were poor. Excellent support from the radar network through timely and accurate radar fix positioning allowed JTWC to track and forecast tropical cyclone movement during even the most erratic track changes.

Nineteen radar reports were received on southern hemisphere tropical cyclones. None were logged for the North Indian Ocean tropical cyclones.

Looking ahead, the Next Generation Weather (Doppler) Radar (NEXRAD) is expected to be operational on Guam and at JTWC in April 1993.

2.5 TROPICAL CYCLONE FIX DATA

A total of 3139 fixes on thirty-two northwest Pacific tropical cyclones and 139 fixes on four North Indian Ocean tropical cyclones were logged at JTWC. Table 2-4A delineates the number of fixes per platform for each individual tropical cyclone for the western North Pacific and North Indian Oceans. Season totals and percentages are also indicated. Table 2-4B provides similar information for the 1487 fixes in the South Pacific and South Indian Oceans.

TABLE 2-4A

1991 NORTHWEST PACIFIC AND NORTH INDIAN OCEAN FIX PLATFORM SUMMARY

NORTHWEST PACIFIC			SATELLITE	RADAR	SYNOPTIC	TOTAL
TS	Sharon	(01W)	122	0	0	122
TY	Tim	(02W)	68	0	0	68
TS	Vanessa	(03W)	97	0	0	97
STY	Walt	(04W)	168	63	1	233*
TY	Yunya	(05W)	70	2	0	72
TY	Zeke	(06W)	79	0	2	81
TY	Amy	(07W)	90	20	0	110
TY	Brendan	(08W)	70	18	0	88
TY	Caitlin	(09W)	125	164	1	290
TS	Enrique	(06E)	19	0	0	19
TS	Doug	(10W)	29	0	0	29
TY	Ellie	(11W)	128	108	0	236
TY	Fred	(12W)	100	6	0	106
TD	13W	(13W)	16	0	0	16
TY	Gladys	(14W)	134	98	3	235
TD	15W	(15W)	52	33	0	85
TS	Harry	(16W)	35	30	0	65
TY	Ivy	(17W)	123	37	0	160
TS	Joel	(18W)	53	46	1	100
TY	Kinna	(19W)	66	83	2	151
TS	Luke	(20W)	77	9	0	86
STY	Mireille	(21W)	164	133	0	298*
TY	Nat	(22W)	196	144	0	340
TY	Orchid	(23W)	143	29	0	172
TY	Pat	(24W)	92	0	0	92
STY	Ruth	(25W)	172	0	0	172
STY	Seth	(26W)	196	19	0	215
TS	Thelma	(27W)	89	2	0	91
TS	Verne	(28W)	79	0	0	79
TS	Wilda	(29W)	72	7	0	79
STY	Yuri	(30W)	132	27	0	159
TY	Zelda	(31W)	83	10	0	93
Totals NWP:			**3139**	**1088**	**10**	**4239***
Percentage of Total:			**74%**	**26%**	**0%**	**100%**

NORTH INDIAN OCEAN			SATELLITE	RADAR	SYNOPTIC	TOTAL
TC	01A	(01A)	26	0	0	26
TC	02B	(02B)	53	0	0	53
TC	03B	(03B)	39	0	0	39
TC	04B	(04B)	21	0	0	21
Totals NIO:			**139**	**0**	**0**	**139**
Percentage of Total:			**100%**	**0%**	**0%**	**100%**

* Two aircraft fixes were received.

TABLE 2-4B **1991 SOUTH PACIFIC AND SOUTH INDIAN OCEANS FIX PLATFORM SUMMARY**

TROPICAL CYCLONES		SATELLITE	SYNOPTIC	RADAR	TOTAL
TC 01S	- - - -	47	0	0	47
TC 02S	- - - -	29	0	0	29
TC 03P	Sina	60	0	0	60
TC 04S	- - - -	21	0	0	21
TC 05S	Laurence	33	0	2	35
TC 06P	Joy	144	0	13	157
TC 07S	Alison	55	0	0	55
TC 08S	Bella	146	0	0	146
TC 09S	Chris	86	0	0	86
TC 10S	Cynthia	9	0	0	9
TC 11S	Daphne	84	0	6	90
TC 12S	Debra	57	0	0	57
TC 13P	Kelvin	124	0	1	125
TC 14S	Elma	50	0	0	50
TC 15P	- - - -	18	0	0	18
TC 16P	- - - -	53	0	0	53
TC 17S	Fatima	84	0	0	84
TC 18S	Errol	88	0	0	88
TC 19S	Marian	119	0	0	119
TC 20S	Fifi	64	0	0	64
TC 21P	Lisa	67	0	0	67
TC 22S	Gritelle	30	0	0	30
Total Number of Fixes:		**1468**	**0**	**22**	**1490**
Percentage of Total:		**99%**	**0%**	**1%**	**100%**

3. SUMMARY OF WESTERN NORTH PACIFIC AND NORTH INDIAN OCEAN TROPICAL CYCLONES

3.1 GENERAL

For the western North Pacific, 1991 was another record-breaking year for the number of warnings issued — 835 (41 more than last year) on 32 tropical cyclones (Table 3-1). If Enrique (06E) which tracked westward from the Eastern Pacific is considered, this was one more than the climatological mean of 31 and a carbon copy of 1990 (Table 3-2). The North Indian Ocean was moderately active with four tropical cyclones, which is just below the climatological average of five. The North Indian Ocean Season included the devastating super cyclone 02B. During the year, a record 891 warnings were issued for 36 tropical cyclones in the Northern Hemisphere. A chronology of activity is provided in Figure 3-1.

In the western North Pacific, JTWC was in warning status 169 days during 1991 compared to 165 in 1990 and 154 in 1989. Again only considering the western North Pacific, there were 47 days when the Center issued warnings on two or more tropical cyclones and 18 days when it warned on three (Table 3-3) at a time. There were no days in the Northern Hemisphere when warnings were issued on four or more tropical cyclones at once. When the North Indian Ocean is included in the total, there were 178 days with warnings on one cyclone and 55 days with two. Thirty-seven initial Tropical Cyclone Formation Alerts were issued on western North Pacific tropical disturbances (Table 3-4) and five on disturbances in the North Indian Ocean. Alerts preceded warnings on all significant tropical cyclones in the western North Pacific and North Indian Ocean with the exception of Tropical Depression 15W and Enrique (06E) which regenerated rather rapidly.

TABLE 3-2 **WESTERN NORTH PACIFIC TROPICAL CYCLONE DISTRIBUTION**

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
1959	0	1	1	1	0	1	3	8	9	3	2	2	31
	000	010	010	100	000	001	111	512	423	210	200	200	17 7 7
1960	1	0	1	1	1	3	3	9	5	4	1	1	30
	001	000	001	100	010	210	210	810	041	400	100	100	19 8 3
1961	1	1	1	1	4	6	5	7	6	7	2	1	42
	010	010	100	010	211	114	320	313	510	322	101	100	20 11 11
1962	0	1	0	1	3	0	8	8	7	5	4	2	39
	000	010	000	100	201	000	512	701	313	311	301	020	24 6 9
1963	0	0	1	1	0	4	5	4	4	6	0	3	28
	000	000	001	100	000	310	311	301	220	510	000	210	19 6 3
1964	0	0	0	0	3	2	8	8	8	7	6	2	44
	000	000	000	000	201	200	611	350	521	331	420	101	26 13 5
1965	2	2	1	1	2	4	6	7	9	3	2	1	40
	110	020	010	100	101	310	411	322	531	201	110	010	21 13 6
1966	0	0	0	1	2	1	4	9	10	4	5	2	38
	000	000	000	100	200	100	310	531	532	112	122	101	20 10 8
1967	1	0	2	1	1	1	8	10	8	4	4	1	41
	010	000	110	100	010	100	332	343	530	211	400	010	20 15 6
1968	0	1	0	1	0	4	3	8	4	6	4	0	31
	000	001	000	100	000	202	120	341	400	510	400	000	20 7 4
1969	1	0	1	1	0	0	3	3	6	5	2	1	23
	100	000	010	100	000	000	210	210	204	410	110	010	13 6 4
1970	0	1	0	0	0	2	3	7	4	6	4	0	27
	000	100	000	000	000	110	021	421	220	321	130	000	12 12 3
1971	1	0	1	2	5	2	8	5	7	4	2	0	37
	010	000	010	200	230	200	620	311	511	310	110	000	24 11 2
1972	1	0	1	0	0	4	5	5	6	5	2	3	32
	100	000	001	000	000	220	410	320	411	410	200	210	22 8 2
1973	0	0	0	0	0	0	7	6	3	4	3	0	23
	000	000	000	000	000	000	430	231	201	400	030	000	12 9 2
1974	1	0	1	1	1	4	5	7	5	4	4	2	35
	010	000	010	010	100	121	230	232	320	400	220	020	15 17 3
1975	1	0	0	1	0	0	1	6	5	6	3	2	25
	100	000	000	001	000	000	010	411	410	321	210	002	14 6 5
1976	1	1	0	2	2	2	4	4	5	0	2	2	25
	100	010	000	110	200	200	220	130	410	000	110	020	14 11 0
1977	0	0	1	0	1	1	4	2	5	4	2	1	21
	000	000	010	000	001	010	301	020	230	310	200	100	11 8 2
1978	1	0	0	1	0	3	4	8	4	7	4	0	32
	010	000	000	100	000	030	310	341	310	412	121	000	15 13 4
1979	1	0	1	1	2	0	5	4	6	3	2	3	28
	100	000	100	100	011	000	221	202	330	210	110	111	14 9 5
1980	0	0	1	1	4	1	5	3	7	4	1	1	28
	000	000	001	010	220	010	311	201	511	220	100	010	15 9 4
1981	0	0	1	1	1	2	5	8	4	2	3	2	29
	000	000	100	010	010	200	230	251	400	110	210	200	16 12 1
1982	0	0	3	0	1	3	4	5	6	4	1	1	28
	000	000	210	000	100	120	220	500	321	301	100	100	19 7 2
1983	0	0	0	0	0	1	3	6	3	5	5	2	25
	000	000	000	000	000	010	300	231	111	320	320	020	12 11 2
1984	0	0	0	0	0	2	5	7	4	8	3	1	30
	000	000	000	000	000	020	410	232	130	521	300	100	16 11 3
1985	2	0	0	0	1	3	1	7	5	5	1	2	27
	020	000	000	000	100	201	100	520	320	410	010	110	17 9 1
1986	0	1	0	1	2	2	2	5	2	5	4	3	27
	000	100	000	100	110	110	200	410	200	320	220	210	19 8 0
1987	1	0	0	1	0	2	4	4	7	2	3	1	25
	100	000	000	010	000	110	400	310	511	200	120	100	18 6 1
1988	1	0	0	0	1	3	2	5	8	4	2	1	27
	100	000	000	000	100	111	110	230	260	400	200	010	14 12 1
1989	1	0	0	1	2	2	6	8	4	6	3	2	35
	010	000	000	100	200	110	231	332	220	600	300	101	21 10 4

TABLE CONTINUED ON TOP OF NEXT PAGE

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YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
1990	1	0	0	0	2	4	4	5	5	5	4	1	32
	100	000	000	000	110	211	220	500	410	230	310	100	21 10 1
1991	0	0	2	1	1	1	4	8	6	3	6	0	32
	000	000	110	010	100	100	400	332	420	300	330	000	20 10 2
(1959-1991)													
MEAN:	0.6	0.3	0.6	0.7	1.3	2.1	4.5	6.2	5.7	4.5	2.9	1.4	30.8
CASES:	19	9	20	24	42	70	148	206	187	150	96	46	1017

The criteria used in Table 3-2 are as follows:

1. If a tropical cyclone was first warned on during the last two days of a particular month and continued into the next month for longer than two days, then that system was attributed to the second month.

2. If a tropical cyclone was warned on prior to the last two days of a month, it was attributed to the first month, regardless of how long the system lasted.

3. If a tropical cyclone began on the last day of the month and ended on the first day of the next month, that system was attributed to the first month. However, if a tropical cyclone began on the last day of the month and continued into the next month for only two days, then it was attributed to the second month.

TABLE 3-2 LEGEND

Legend: Total for the month → **6**

Typhoons → **3**

Tropical Storms → **1**

Tropical Depressions → **2**

TABLE 3-1

WESTERN NORTH PACIFIC SIGNIFICANT TROPICAL CYCLONES FOR 1991

TROPICAL CYCLONE		PERIOD OF WARNING	NUMBER OF WARNINGS ISSUED	MAXIMUM SURFACE WINDS KT (M/SEC)	ESTIMATED MSLP (MB)
(01W)	TS SHARON	05 MAR - 14 MAR	33	60 (31)	980
(02W)	TY TIM	21 MAR - 25 MAR	20	70 (36)	972
(03W)	TS VANESSA	23 APR - 28 APR	20	45 (23)	991
(04W)	STY WALT	06 MAY - 16 MAY	40	140 (72)	898
(05W)	TY YUNYA	13 JUN - 17 JUN	16	105 (54)	938
(06W)	TY ZEKE	09 JUL - 14 JUL	21	80 (41)	963
(07W)	TY AMY	15 JUL - 20 JUL	18	125 (64)	916
(08W)	TY BRENDAN	21 JUL - 24 JUL	16	70 (36)	972
(09W)	TY CAITLIN	23 JUL - 30 JUL	27	95 (49)	949
(06E)	TS ENRIQUE	01 AUG - 01 AUG	3	35 (18)	997
(10W)	TS DOUG	08 AUG - 11 AUG	9	35 (18)	997
(11W)	TY ELLIE	10 AUG - 19 AUG	34	85 (44)	958
(12W)	TY FRED	11 AUG - 18 AUG	27	95 (49)	949
(13W)	TD 13W	12 AUG - 13 AUG	5	25 (13)	1004
(14W)	TY GLADYS	16 AUG - 23 AUG	31	65 (33)	973
(15W)	TD 15W	26 AUG - 29 AUG	11	30 (15)	997
(16W)	TS HARRY	29 AUG - 31 AUG	10	40 (21)	994
(17W)	TY IVY	02 SEP - 10 SEP	32	115 (59)	927
(18W)	TS JOEL	03 SEP - 07 SEP	15	55 (28)	982
(19W)	TY KINNA	10 SEP - 14 SEP	17	90 (46)	954
(20W)	TS LUKE	14 SEP - 19 SEP	20	50 (26)	987
(21W)	STY MIREILLE	16 SEP - 27 SEP	48	130 (67)	910
(22W)	TY NAT	16 SEP - 02 OCT	61	110 (57)	933
(23W)	TY ORCHID	04 OCT - 13 OCT	37	115 (59)	927
(24W)	TY PAT	05 OCT - 13 OCT	31	125 (64)	916
(25W)	STY RUTH	20 OCT - 31 OCT	40	145 (75)	892
(26W)	STY SETH	01 NOV - 14 NOV	56	130 (67)	910
(27W)	TS THELMA	01 NOV - 08 NOV	23	45 (23)	991
(28W)	TS VERNE	05 NOV - 12 NOV	28	55 (28)	984
(29W)	TS WILDA	14 NOV - 20 NOV	22	45 (23)	991
(30W)	STY YURI	23 NOV - 01 DEC	36	150 (77)	885
(31W)	TY ZELDA	27 NOV - 04 DEC	28	80 (41)	963
		TOTAL:	835		

Figure 3-1. Chronology of western North Pacific and North Indian Ocean tropical cyclones for 1991.

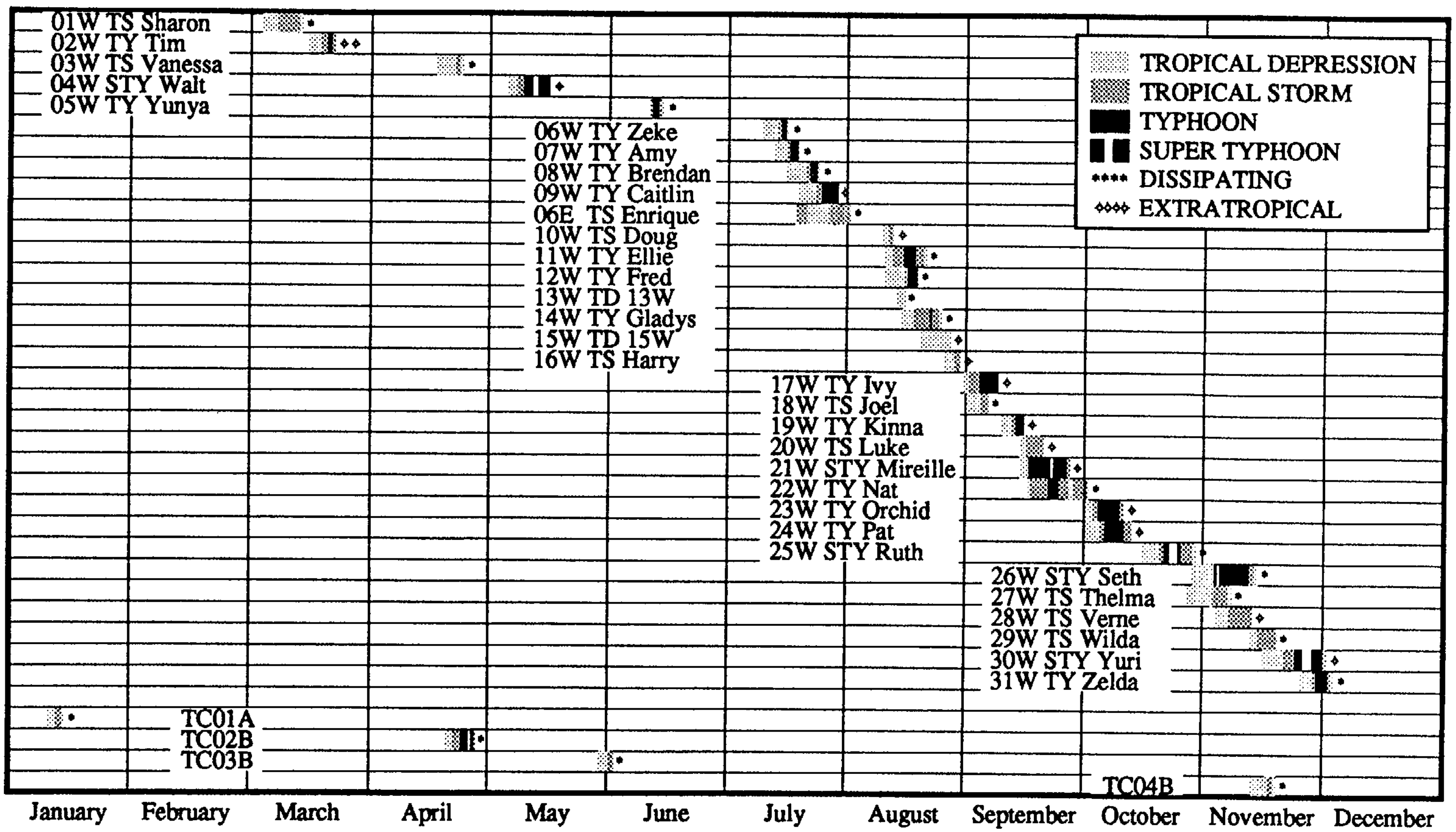


TABLE 3-3 **WESTERN NORTH PACIFIC TROPICAL CYCLONES**

TYPHOONS

(1945 - 1959)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN:	0.3	0.1	0.3	0.4	0.7	1.0	2.9	3.1	3.3	2.4	2.0	0.9	16.4
CASES:	5	1	4	6	10	15	29	46	49	36	30	14	245

(1960 - 1991)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN:	0.3	0.1	0.2	0.5	0.7	1.1	2.7	3.2	3.2	3.1	1.8	0.6	17.5
CASES:	9	2	7	15	24	35	88	102	104	100	57	20	563

TROPICAL STORMS AND TYPHOONS

(1945 - 1959)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN:	0.4	0.1	0.5	0.5	0.8	1.6	2.9	4.0	4.2	3.3	2.7	1.2	22.2
CASES:	6	2	7	8	11	22	44	60	64	49	41	18	332

(1960 - 1991)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN:	0.6	0.3	0.5	0.7	1.1	1.8	4.2	5.3	5.0	4.2	2.7	1.2	27.3
CASES:	18	8	15	22	36	59	133	171	159	133	88	38	880

NUMBER OF CALENDAR WARNING DAYS: 169
NUMBER OF CALENDAR WARNING DAYS WITH TWO TROPICAL CYCLONES: 47
NUMBER OF CALENDAR WARNING DAYS WITH THREE TROPICAL CYCLONES:18

TABLE 3-4 **TROPICAL CYCLONE FORMATION ALERTS**
WESTERN NORTH PACIFIC OCEAN

YEAR	INITIAL TCFAS	TROPICAL CYCLONES WITH TCFAS	TOTAL TROPICAL CYCLONES	FALSE ALARM RATE	PROBABILITY OF DETECTION
1976	34	25	25	26%	100%
1977	26	20	21	23%	95%
1978	32	27	32	16%	84%
1979	27	23	28	15%	82%
1980	37	28	28	24%	100%
1981	29	28	29	3%	96%
1982	36	26	28	28%	93%
1983	31	25	25	19%	100%
1984	37	30	30	19%	100%
1985	39	26	27	33%	96%
1986	38	27	27	29%	100%
1987	31	24	25	23%	96%
1988	33	26	27	21%	96%
1989	51	32	35	37%	91%
1990	33	30	31	9%	97%
1991	37	29	31*	22%	94%
(1976-1991)					
MEAN:	34.4	26.6	28.1	23%	95%
TOTALS:	551	426	449		

1991 FORMATION ALERTS: 30 OF 32 INITIAL FORMATION ALERTS DEVELOPED INTO SIGNIFICANT TROPICAL CYCLONES.
* ENRIQUE(06E) NOT INCLUDED

3.2 WESTERN NORTH PACIFIC TROPICAL CYCLONES

The 12 months of 1991 included five super typhoons, 15 lesser typhoons, 10 tropical storms and two tropical depressions. Again, like the preceding 2 years, this was above average for the number of typhoons and super typhoons, but below average for tropical depressions. A possible record number of five midget tropical cyclones occurred during the year. All tropical cyclones originated in the monsoon trough, near-equatorial trough, or within a Northward-displaced Self-sustaining, Solitary (NSS) monsoon gyre* (Lander, 1992) which dominated the circulation of the western North Pacific during August. None were TUTT-induced, even though the TUTT was much in evidence during the summer.

January and February were months with a very active Australian monsoon and higher than normal surface pressures in the western North Pacific. This pattern changed dramatically in March as pressures rose across northern Australia with the demise of the monsoon. Coincident with the Southern Oscillation Index for March going negative, brisk equatorial westerlies appeared east of New Guinea and cyclonic vortices (including Sharon (01W) and Tim (02W)) formed both north and south of the equator in the twin near-equatorial troughs. These anomalously strong westerly winds continued into April and May, and supported the formation of Vanessa (03W) and Walt (04W) as well. In early May, a strong west-wind burst along the equator led to the formation of Walt (04W) and a southern twin (Lisa (21P)). In June and July, a single monsoon trough became established in the western North Pacific and a near-equatorial buffer zone appeared, as the southern hemisphere near-equatorial trough was replaced by southeasterly flow. With the exception of Enrique (06E), which came westward across the international date line, tropical cyclones Yunya (05W) through Caitlin (09W) developed in this northern hemisphere trough.

After 31 July, when Caitlin dissipated, almost 2 weeks followed without tropical cyclone activity as a major synoptic pattern change occurred in the western North Pacific - a NSS monsoon gyre replaced the normal monsoon trough. In August (Figure 3-2), with the exception of Fred (12W), which developed just east of the central Philippine Islands in an extension of the Asian monsoon trough , Doug (10W) through Harry (16W) formed in the NSS monsoon gyre.

In September (Figure 3-3), after the demise of Harry (16W) and the NSS monsoon gyre, there was another major synoptic pattern change - the monsoon trough reappeared in low latitudes. This trough spawned Ivy (17W) and the remaining tropical cyclones of the year. Starting in October (Figure 3-4), with a moderate El Niño taking shape in the Central Pacific, persistent convection and strong equatorial westerlies became established east of New Guinea. By November, most of the deep convective clouds had moved back along the equator and the twin near-equatorial troughs were established again with named cyclones forming both north and south of the equator.

*Monsoon gyres are modes of the monsoon circulation which are characterized by:
1) a large (diameter on the order of 1000 nm (2000 km)) nearly circular low-level cyclonic vortex;
2) nearly circular isobars with the outermost closed isobar possessing a diameter of roughly 1000 nm (2000 km);
3) a northward displacement of the sea-level pressure minimum with respect to the latitude of the pressure minimum found along any meridian passing through the long-term monthly mean monsoon trough; and
4) lower than average sea-level pressure throughout most of the tropical western North Pacific.

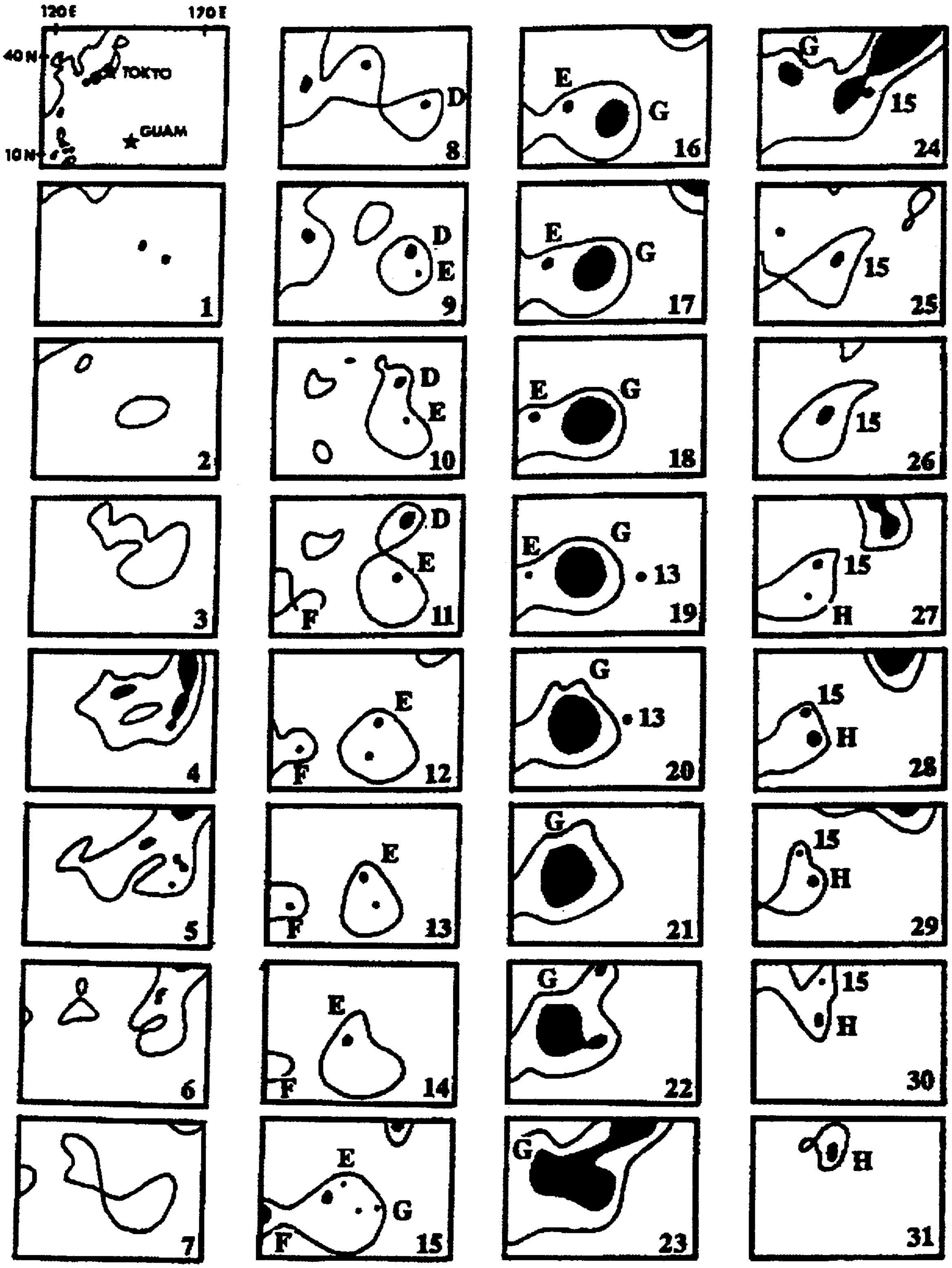


Figure 3-2. Western North Pacific sea-level pressure for August 1991. Outer contour is 1006 mb; black-shaded regions: < 1000 mb. Maps are at 00Z for the date indicated in the lower right of each panel. Geography key appears in upper left panel. Tropical cyclones are indicated: D-Doug (10W), E-Ellie (11W), F-Fred (12W), 13-Tropical Depression 13W, G-Gladys (14W), 15-Tropical Depression 15W and H-Harry (16W). (Adapted from Lander, 1992.)

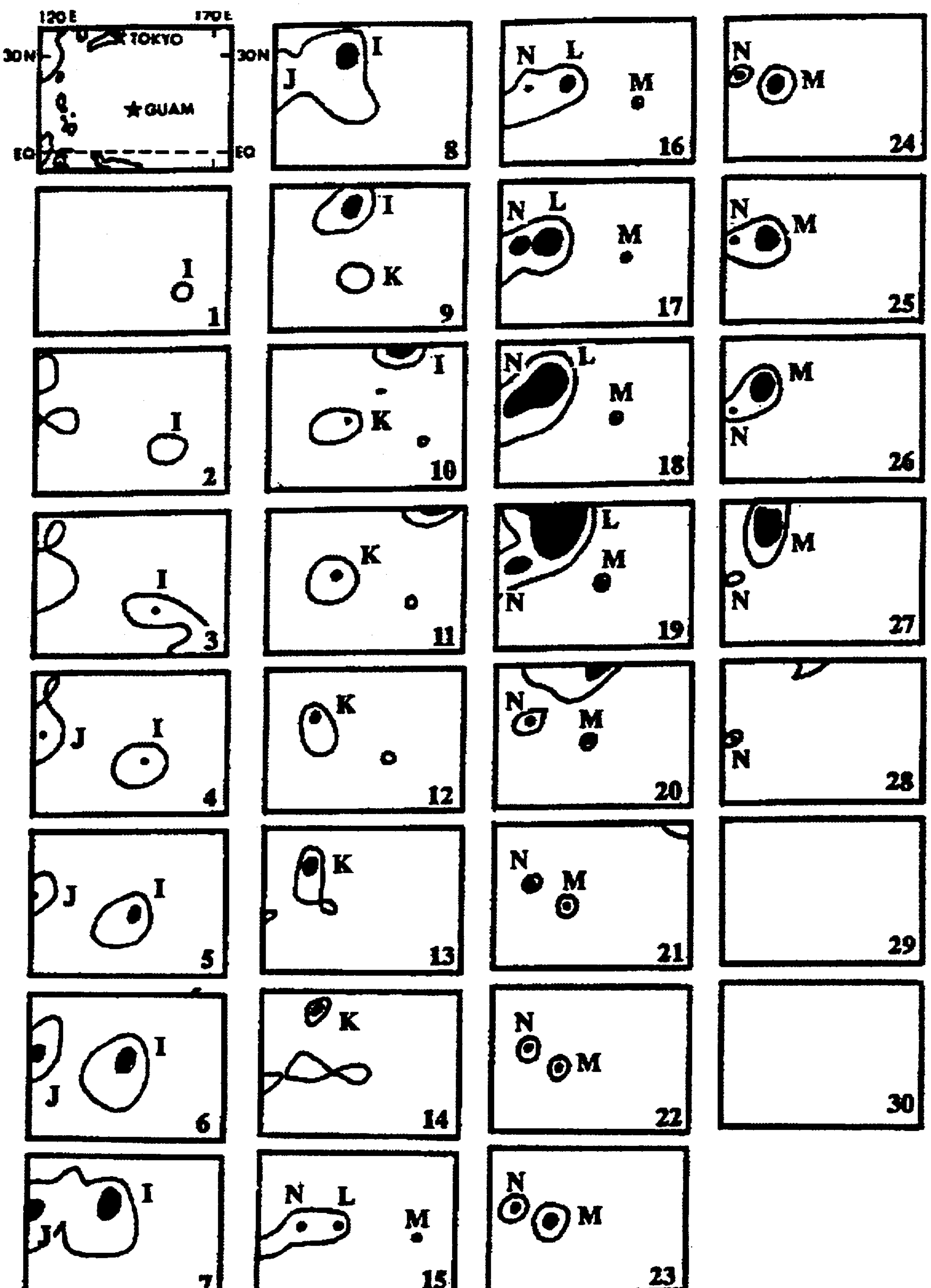


Figure 3-3. Western North Pacific sea-level pressure for September 1991. Outer contour is 1008 mb; black-shaded regions: < 1002 mb. Maps are at 00Z for the date indicated in the lower right of each panel. Geography key appears in upper left panel. Tropical cyclones are indicated: I-Ivy (17W), J-Joel (18W), K-Kinna (19W), L-Luke (20W), M-Mireille (21W) and N-Nat (22W). (Adapted from Lander, 1992.)

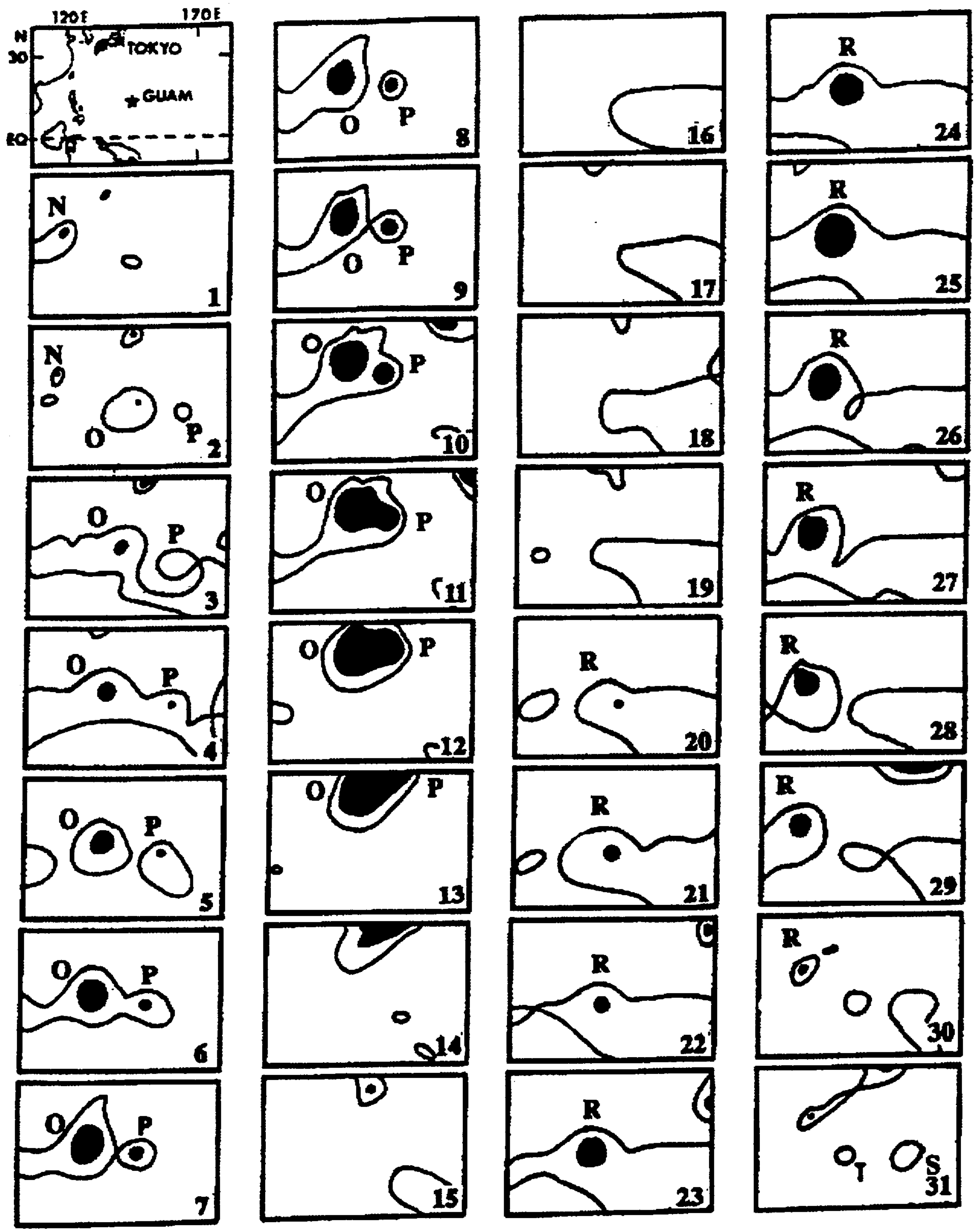


Figure 3-4. Western North Pacific sea-level pressure for October 1991. Outer contour is 1010 mb; black-shaded regions: < 1004 mb. Maps are at 00Z for the date indicated in the lower right of each panel. Geography key appears in upper left panel. Tropical cyclones are indicated: N-Nat (22W), O-Orchid (23W), P-Pat (24W), R-Ruth (25W), S-Seth (26W) and T-Thelma (27W). (Adapted from Lander, 1992.)

JANUARY THROUGH JUNE

The first tropical cyclone of 1991 in the western North Pacific, **Sharon (01W)**, developed the first week of March in conjunction with a burst of equatorial westerly winds that extended eastward from New Guinea to the international date line. Sharon tracked over the central Philippine Islands and continued westward across the South China Sea to dissipate in southeastern Vietnam on 16 March. Close behind Sharon, **Tim (02W)** was the second tropical cyclone to develop in the eastern Caroline Islands during the month of March. The recurvature track taken by Tim proved difficult to predict for JTWC forecasters, because the primary prognostic guidance was slow to depict the changing synoptic situation. Average forecast errors for Tim were the largest of any Northwest Pacific tropical cyclone forecasts in 1991. After Typhoon Tim in mid-March, the near-equatorial trough remained relatively inactive until **Vanessa's (03W)** convection flared up to the south of Guam over a month later. Vanessa moved across the central Philippine Islands as a weak tropical depression, peaked at 45 kt (23 m/sec) in the South China Sea, then the remnants of the tropical storm moved northward through the axis of the subtropical ridge and dissipated southwest of Hong Kong. A week later, **Walt (04W)** generated below 5° North Latitude in the eastern Caroline Islands. Walt was the first super typhoon of the year in the western North Pacific and the only significant tropical cyclone to form in May. It developed as part of an equatorial convective process known as a "westerly burst" (Lander, 1990) at the same time a twin, Tropical Cyclone 21P (Lisa), developed in the Southern Hemisphere. Almost a month later, Typhoon **Yunya (05W)** followed as the first significant tropical cyclone of June, breaking a nearly month-long lull in activity in the western North Pacific. Yunya was noteworthy because a ship transited through its center, providing a unique glimpse of the structure of a rapidly-developing, midget typhoon. Its passage through central Luzon coincided with the massive eruption of Mount Pinatubo and evacuation of personnel from Clark Air Base.

JULY

Two-and-one-half weeks after Yunya dissipated, **Zeke (06W)** evolved in the Philippine Sea. Zeke was the first tropical cyclone to develop during the month of July, and initiated a period of nearly continuous tropical cyclone warning status for JTWC in the Northwest Pacific through early December. Typhoon Zeke made landfall three times before it dissipated over the mountains of northern Vietnam. The second of five tropical cyclones to form in July, **Amy (07W)** followed a west-northwesterly track that paralleled the one taken a week earlier by Typhoon Zeke (06W). Near Taiwan, the typhoon caused the loss of the 16,000 ton freighter, **Blue River**, with its entire crew, and then became the deadliest typhoon of the year to strike China. **Brendan (08W)** was the third straight-runner in a row. Torrential rains associated with the tropical cyclone's passage across northern Luzon unleashed lahars or avalanches of volcanic debris, mud and boulders in the valleys near Mount Pinatubo.

After a succession of three straight-running July typhoons (Zeke (06W), Amy (07W), and Brendan(08W)) which moved west-northwestward, **Caitlin (09W)** became the first cyclone of the season to threaten Japan and Korea. Much-needed heavy rains fell on drought-stricken Okinawa as Caitlin passed west of the island. Then, **Enrique (06E)**, a rare tropical cyclone which began in the Eastern Pacific and trekked 4900 nm (9100 km) across the central North Pacific Ocean, regenerated, reached minimum tropical storm intensity, and then dissipated in the JTWC area

of responsibility. Over the past 20 years, Typhoon Georgette (1986) was the only other Eastern Pacific tropical cyclone to cross the international date line.

AUGUST

Doug (10W) was the first of a series of six tropical cyclones to form in August as part of a large NSS monsoon gyre. Doug failed to intensify beyond minimal tropical storm intensity because it moved rapidly northward into an area of colder sea surface temperatures and increased vertical wind shear before transitioning into an extratropical cyclone. The second tropical cyclone of August, **Ellie (11W)**, formed as part of the larger NSS monsoon gyre a day after Doug. Ellie, was also the second midget typhoon of 1991. It maintained a generally westward track, traveling 2400 nm (4440 km) across the western North Pacific from just west of Wake Island to Taiwan. Next came **Fred (12W)** which was spawned by the Asian monsoon trough and became part one of two, three-storm outbreaks that occurred in mid-August. Typhoon Fred skirted the northern coasts of Luzon and Hainan Island before dissipating over Southeast Asia. **Tropical Depression 13W** formed as a low pressure area in the same NSS monsoon gyre as Typhoon Ellie, then tracked northwestward in Ellie's wake. Tropical Depression 13W was marked by large diurnal fluctuations in convection which slowed the development of strong surface winds. The fourth and largest of six tropical cyclones generated by the NSS monsoon gyre active during the month of August was Typhoon **Gladys (14W)**. Gladys' wind field expanded dramatically with only a small change in minimum sea-level pressure as it tracked south of Korea and western Japan. Gladys was a good example of a cyclone that "strengthened" but did not "intensify" significantly. When animated satellite imagery indicated cyclonic turning in an area of deep convection associated with the NSS monsoon gyre, a Significant Tropical Weather Advisory was reissued at 212200Z (August) to include the disturbance that was to become **Tropical Depression 15W**. Five days later **Harry (16W)** became the last of six tropical cyclones, beginning with Doug (10W) three weeks earlier, to generate within this NSS monsoon gyre.

SEPTEMBER THROUGH DECEMBER

Ivy (17W) was the first tropical cyclone since Fred to form in the monsoon trough which re-established itself eastward from Asia through the Caroline Islands. Ivy was also the first significant threat of the typhoon season for the Mariana Islands. For 4 days, the tropical cyclone tracked west-northwestward, straight towards Guam, then on 4 September it took a sudden, unanticipated turn to the north-northwest and headed for the Northern Marianas and subsequently Japan. **Joel (18W)** developed in the South China Sea, tracked westward, and then came to an abrupt halt. After little, or no, movement for six hours, the tropical cyclone slowly inched northward and made landfall 70 nm (130 km) east of Hong Kong. A day later, **Kinna (19W)** formed in the western Caroline Islands. It was the most destructive tropical cyclone to strike Okinawa since 1987, and the first typhoon to pass directly across the island since Vera in 1986. Later, the typhoon also passed directly across Sasebo, Japan, and caused extensive damage on Kyushu and later Honshu as it raced northeastward after recurvature. The exceptionally accurate forecasts of the path taken by Typhoon Kinna provided more than ample lead time for disaster preparation at key DOD installations. As Kinna became extratropical, Tropical Storm **Luke (20W)** formed just east of the Mariana Islands. It was a broad monsoonal cyclone, difficult to track

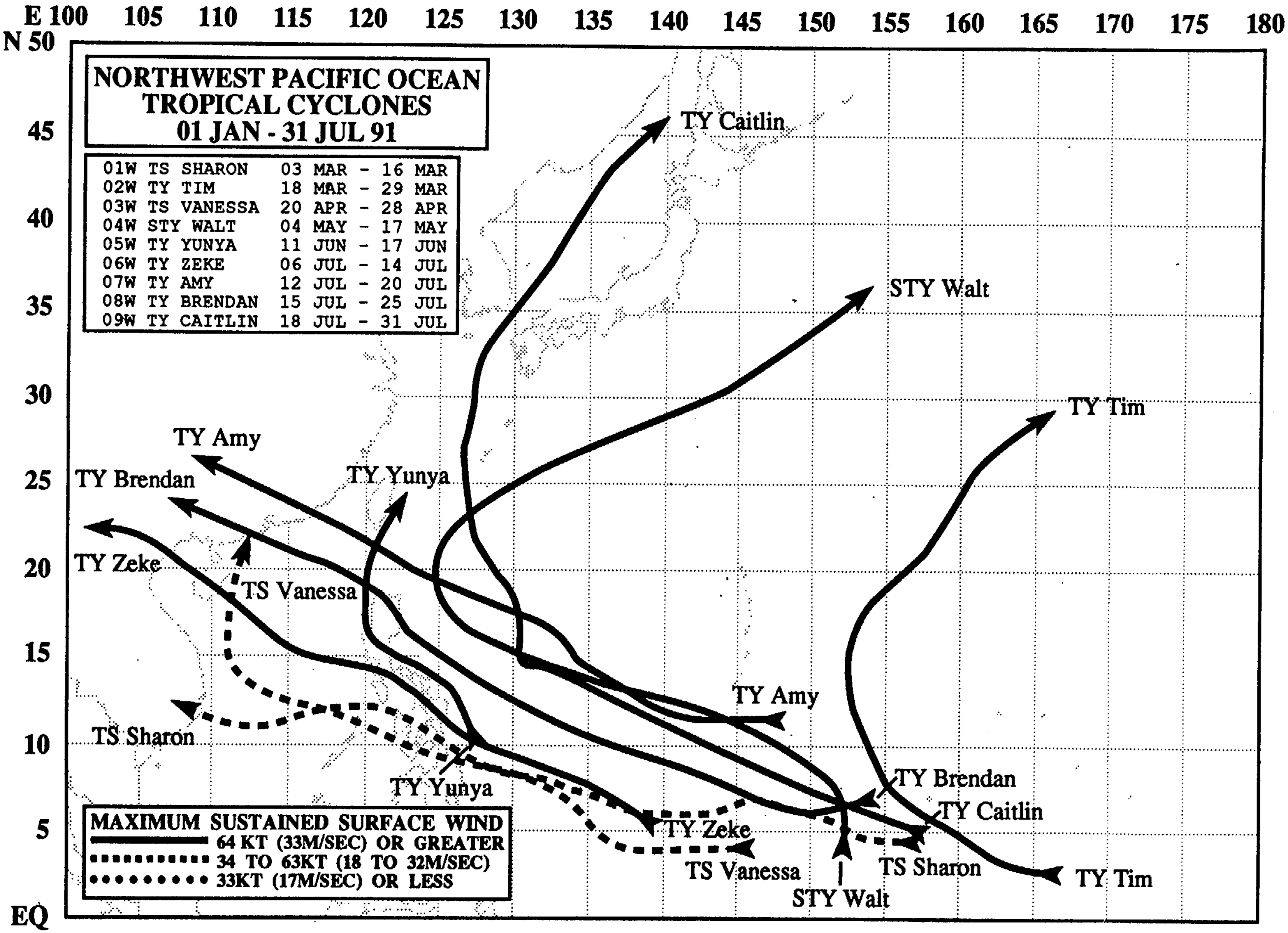
by satellite, and had the largest initial position errors of the season. Luke's unusual recurvature track resulted from the extension of the mid-latitude, mid-tropospheric westerlies deep into the tropics in mid-September, which temporarily broke down the subtropical ridge in the western Pacific.

Mireille (21W) was part of a three storm outbreak in September consisting of Tropical Storm Luke (20W) and Typhoon Nat (22W). Later, after Luke had become extratropical, Mireille, Nat and Typhoon Orchid (23W) became part of another three storm outbreak. Mireille was the second super typhoon of the year in the Northwest Pacific, and became the worst storm to strike Japan in three decades. It outgrew it's early midget size after passing Saipan, and reached super typhoon intensity several days before threatening Okinawa. Recurving just to the southwest of Okinawa, the typhoon accelerated, cutting a path across western Kyushu and Honshu. Over the Sea of Japan, Mireille transitioned into an intense extratropical cyclone which slammed into northern Honshu and southern Hokkaido producing gusts to 83 kt (43 m/sec) at Misawa AB. For 17 days, Typhoon **Nat (22W)** exhibited highly erratic behavior which included four major track changes, two intensification episodes, and two landfalls. It persisted longer than any other western North Pacific tropical cyclone during 1991, requiring a total of 61 warnings which was only 18 warnings shy of the all-time record set by Typhoon Rita (1972). Nat's track and behavior were reminiscent of that of Typhoon Wayne (1986).

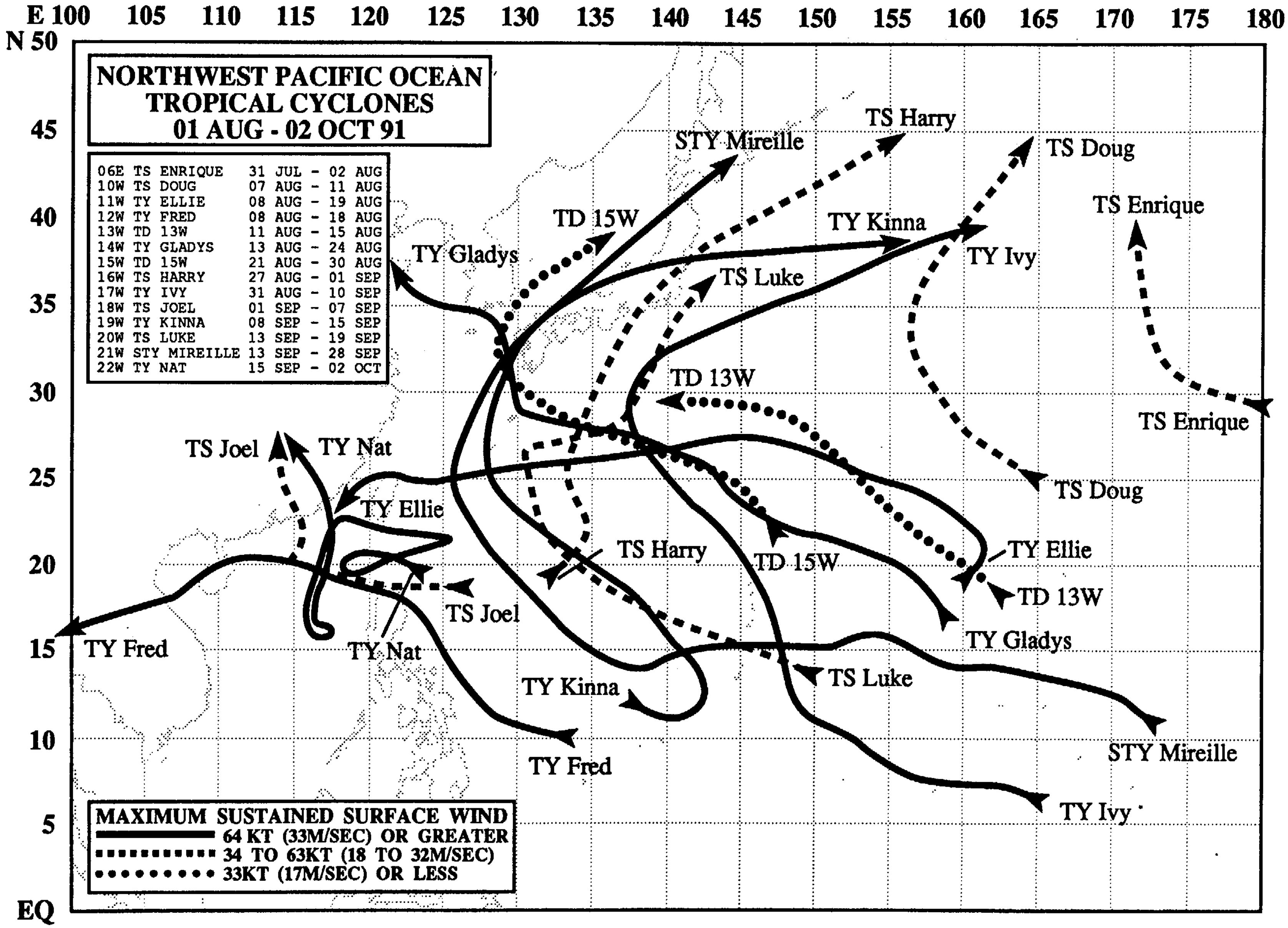
Typhoon **Orchid (23W)** was the first tropical cyclone to develop during the month of October, and was followed within a day by Typhoon Pat (24W). As these two typhoons interacted, Orchid slowed about 200 nm (370 km) off the coast of Japan, and caused widespread flooding in Tokyo and surrounding cities. Developing at the same time in early October as Orchid, Typhoon **Pat's (24W)** track paralleled that of Orchid's, but several hundred miles to the east. Pat's rapid intensification phase was correctly predicted by a recently developed pixel-counting forecast scheme. Two days after Orchid and Pat went extratropical east of Japan, **Ruth (25W)** developed in the eastern Caroline Islands. Super Typhoon Ruth was the second most intense tropical cyclone of 1991. Climatological analogs enabled forecasters to anticipate Ruth's rapid deepening to super typhoon intensity in the Philippine Sea. However, track forecasts based on the NOGAPS spectral model were 2 days early in predicting recurvature. This resulted in the largest forecast track errors of the year as Ruth slammed into northern Luzon instead of recurving toward the Ryukyu Islands. As Ruth finally recurved, Super Typhoon **Seth (26W)** started cranking up in the southern Marshall Islands. It was the first of six tropical cyclones of at least typhoon intensity to occur in the month of November. This was the most active November in the western North Pacific since 1964 when six occurred. Forecasts for Seth's generally westward track were complicated by the normally reliable objective guidance, that in Seth's case, indicated recurvature which did not occur. When Seth formed, **Thelma (27W)** slowly intensified in the central Caroline Islands. The worst loss of life due to a natural disaster in the western North Pacific during 1991 occurred when Tropical Storm Thelma made landfall in the central Philippine islands. News accounts estimated that 6000 people died and 20,000 people were made homeless by landslides, flash flooding, and the failure of a dam. The highest casualties occurred on Leyte and Negros Islands where widespread logging had stripped the hills bare of vegetation.

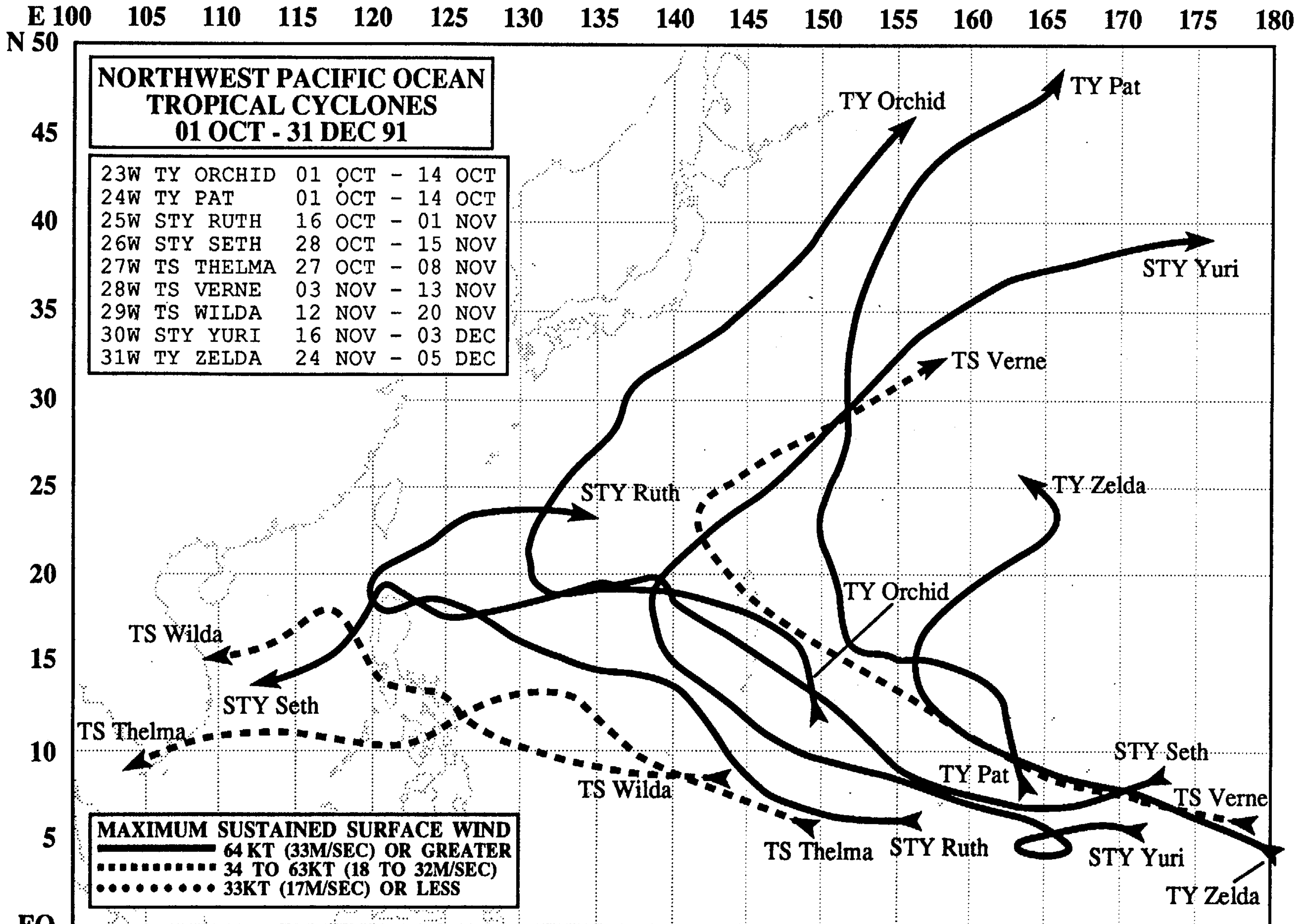
On 3 November, westerly low-level

winds along the equator and a persistent cloud system near the international date line generated the tropical disturbance which eventually became Tropical Storm **Verne (28W)**. Tropical Storm Verne passed between Pagan and Agrihan in the northern Mariana Islands with a maximum intensity of 55 kt (28 m/sec), and closed to within 800 nm (1480 km) of Super Typhoon Seth (26W) on 10 November, before recurving northeastward on 11 November. As Verne transitioned into an extratropical low, **Wilda (29W)** got started in the western Caroline Islands. Tropical Storm Wilda was another midget tropical cyclone, and posed another serious threat to the central Philippine Islands which were devastated by Tropical Storm Thelma (27W) only 2 weeks before. Wilda maintained its peak intensity of 45 kt (23 m/sec) as it tracked across southern Luzon and passed about 40 nm (75 km) south of Manila around noon on 17 November. Due to its compact wind field, damage was minimal near Manila. After turning northwestward later on 17 November, Wilda began to weaken, and on 19 November the residual low-level circulation drifted southwestward with the prevailing northeast monsoon. By the time Wilda had dissipated, **Yuri (30W)** had formed in the southern Marshall Islands and was slowly intensifying. Super Typhoon Yuri was the most intense tropical cyclone of the year, with maximum sustained winds estimated at 150 kt (77 m/sec) and an estimated minimum sea-level pressure of 885 mb. It also was the most intense cyclone to pass within 60 nm (110 km) of Guam since Typhoon Karen (1962). Yuri's steady rate of intensification to a super typhoon without an episode of explosive deepening was unusual. High water and waves caused extensive damage to low-lying areas in the southeastern part of Guam. Yuri was also the largest typhoon to affect the western North Pacific in many years, growing to a diameter of over 900 nm (1665 km) a day after passing Guam. As Yuri bore down on Guam, **Zelda (31W)** developed in low latitudes near the international date line. Typhoon Zelda was the last tropical cyclone of the year, and the fifth midget. Intensification during the early stages of its development was overlooked because of its very small size. Zelda caused considerable damage to the lightly constructed buildings and homes on Kwajalein and the nearby islands and atolls, and caused several injuries.



NORTHWEST PACIFIC OCEAN
TROPICAL CYCLONES
01 JAN - 31 JUL 91
01W TS SHARON 03 MAR - 16 MAR
02W TY TIM 18 MAR - 29 MAR
03W TS VANESSA 20 APR - 28 APR
04W STY WALT 04 MAY - 17 MAY
05W TY YUNYA 11 JUN - 17 JUN
06W TY ZEKE 06 JUL - 14 JUL
07W TY AMY 12 JUL - 20 JUL
08W TY BRENDAN 15 JUL - 25 JUL
09W TY CAITLIN 18 JUL - 31 JUL
E 100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
N 50
45
40
35
30
25
20
15
10
5
EQ
TY Caitlin
STY Walt
TY Tim
TY Amy
TY Brendan
TY Yunya
TY Zeke
TS Vanessa
TS Sharon
TY Amy
TY Yunya
TY Brendan
TY Caitlin
TY Zeke
TS Vanessa
STY Walt
TS Sharon
TY Tim
MAXIMUM SUSTAINED SURFACE WIND
64 KT (33M/SEC) OR GREATER
34 TO 63KT (18 TO 32M/SEC)
33KT (17M/SEC) OR LESS


NORTHWEST PACIFIC OCEAN
TROPICAL CYCLONES
01 AUG - 02 OCT 91
06E TS ENRIQUE 31 JUL - 02 AUG
10W TS DOUG 07 AUG - 11 AUG
11W TY ELLIE 08 AUG - 19 AUG
12W TY FRED 08 AUG - 18 AUG
13W TD 13W 11 AUG - 15 AUG
14W TY GLADYS 13 AUG - 24 AUG
15W TD 15W 21 AUG - 30 AUG
16W TS HARRY 27 AUG - 01 SEP
17W TY IVY 31 AUG - 10 SEP
18W TS JOEL 01 SEP - 07 SEP
19W TY KINNA 08 SEP - 15 SEP
20W TS LUKE 13 SEP - 19 SEP
21W STY MIREILLE 13 SEP - 28 SEP
22W TY NAT 15 SEP - 02 OCT
MAXIMUM SUSTAINED SURFACE WIND
64 KT (33M/SEC) OR GREATER
34 TO 63KT (18 TO 32M/SEC)
33KT (17M/SEC) OR LESS
E 100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
N 50
45
40
35
30
25
20
15
10
5
EQ
STY Mireille
TS Harry
TS Doug
TS Enrique
TD 15W
TY Kinna
TY Gladys
TS Luke
TY Ivy
TD 13W
TS Enrique
TS Joel
TY Nat
TY Ellie
TS Doug
TS Harry
TY Ellie
TD 15W
TD 13W
TS Joel
TY Fred
TY Nat
TY Gladys
TS Luke
TY Kinna
STY Mireille
TY Fred
TY Ivy



NORTHWEST PACIFIC OCEAN
TROPICAL CYCLONES
01 OCT - 31 DEC 91
23W TY ORCHID 01 OCT - 14 OCT
24W TY PAT 01 OCT - 14 OCT
25W STY RUTH 16 OCT - 01 NOV
26W STY SETH 28 OCT - 15 NOV
27W TS THELMA 27 OCT - 08 NOV
28W TS VERNE 03 NOV - 13 NOV
29W TS WILDA 12 NOV - 20 NOV
30W STY YURI 16 NOV - 03 DEC
31W TY ZELDA 24 NOV - 05 DEC
MAXIMUM SUSTAINED SURFACE WIND
64 KT (33M/SEC) OR GREATER
34 TO 63KT (18 TO 32M/SEC)
33KT (17M/SEC) OR LESS
E 100
105
110
115
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125
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180
N 50
45
40
35
30
25
20
15
10
5
EQ
TY Orchid
TY Pat
STY Yuri
TS Verne
TY Zelda
STY Ruth
TY Orchid
TS Wilda
STY Seth
TS Thelma
TS Wilda
TY Pat
STY Seth
TS Verne
TS Thelma
STY Ruth
STY Yuri
TY Zelda

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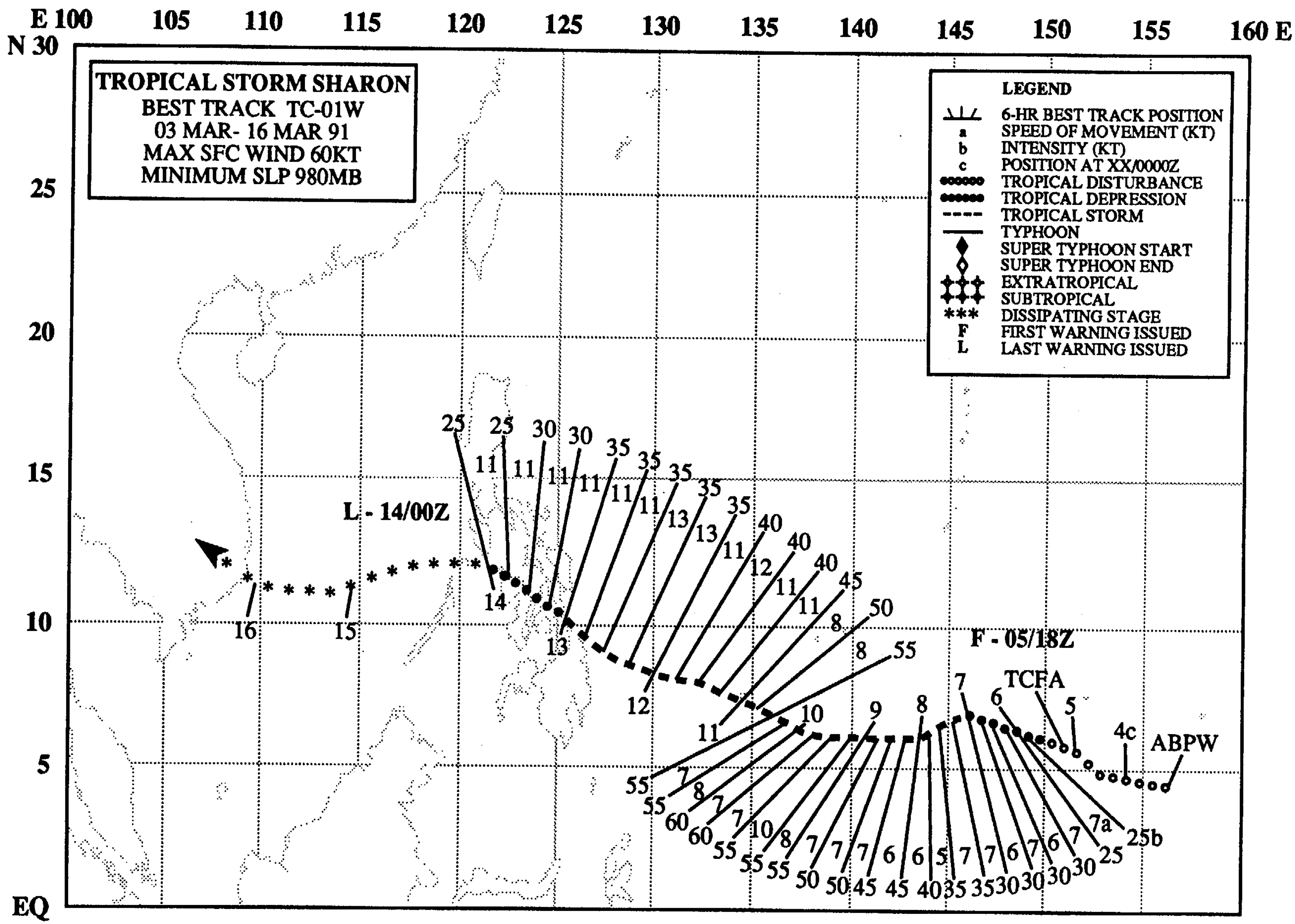


TROPICAL STORM SHARON
BEST TRACK TC-01W
03 MAR- 16 MAR 91
MAX SFC WIND 60KT
MINIMUM SLP 980MB
LEGEND
6-HR BEST TRACK POSITION
SPEED OF MOVEMENT (KT)
INTENSITY (KT)
POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
L - 14/00Z
F - 05/18Z
TCFA
ABPW
E 100
105
110
115
120
125
130
135
140
145
150
155
160 E
N 30
25
20
15
10
5
EQ

TROPICAL STORM SHARON (01W)

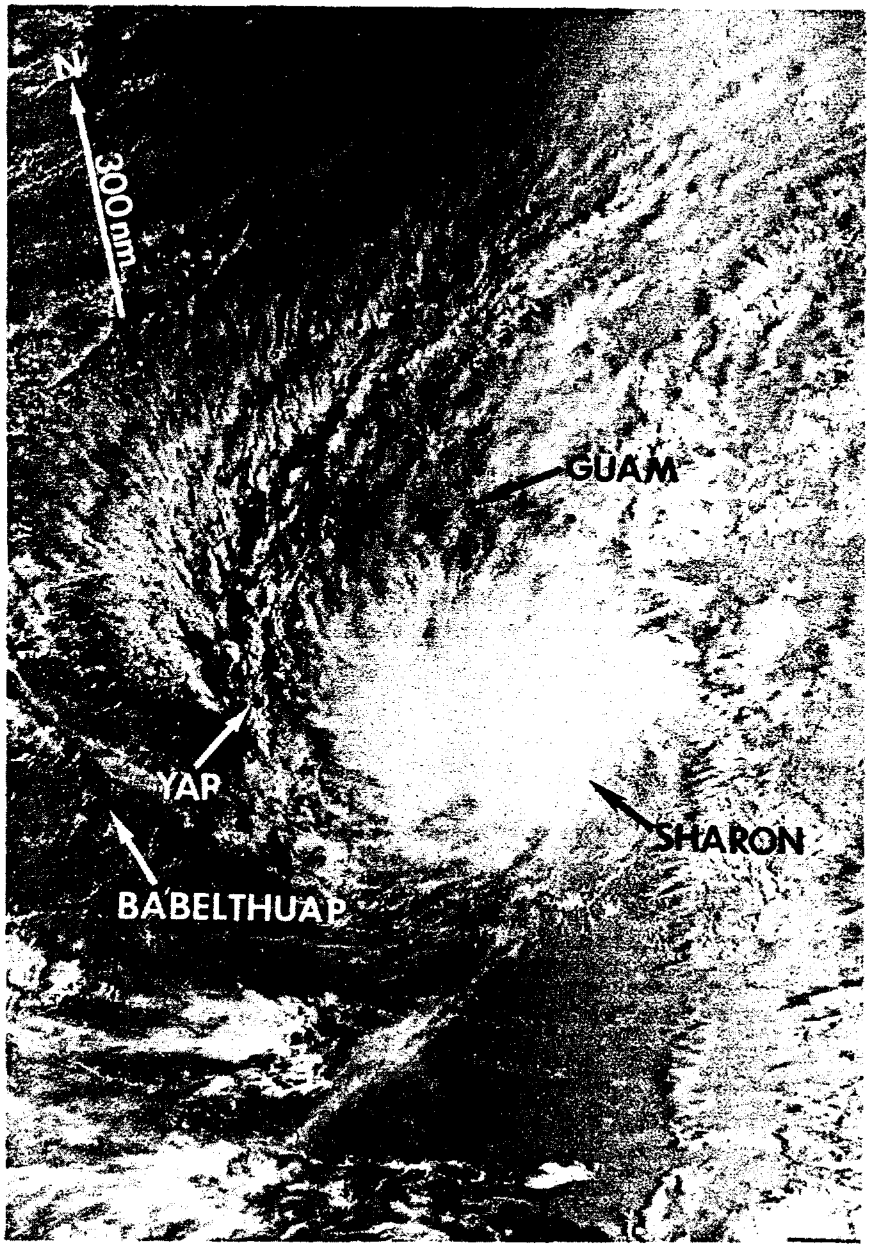
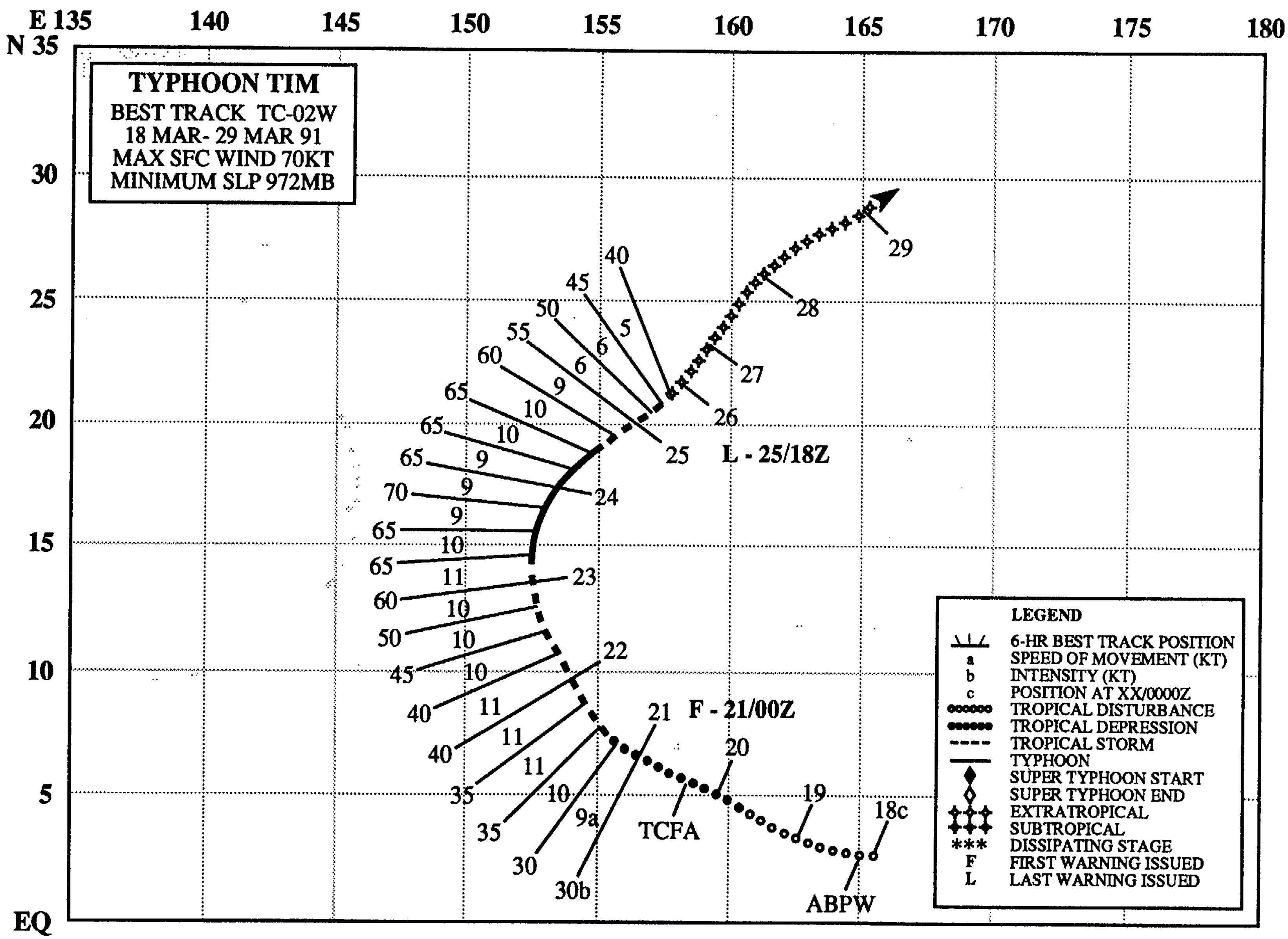


Figure 3-01-1. Tropical Storm Sharon near peak intensity east of Yap (062234Z March DMSP visual imagery).

Sharon, the first tropical cyclone of 1991 in the western North Pacific, developed the first week of March in conjunction with a burst of low-level westerly winds that extended eastward along the equator from New Guinea to the international date line. Its persistent convection was initially discussed on the 030600Z Significant Tropical Weather Advisory. Increased deep convection around the partially exposed low-level circulation center prompted the issuance of the 050451Z Tropical Cyclone Formation Alert. The tropical cyclone developed slowly due to persistent upper level shear on the eastern side of the convective cloud mass. The first warning, valid at 051800Z, did not forecast further intensification to a tropical storm because of the amount of shear evident from satellite imagery. However, as Sharon tracked steadily westward, it reached a peak intensity of 60 kt (30 m/sec) south of Yap before the central dense overcast sheared apart east of Belau. Koror (WMO 91408) reported light winds as the broad circulation center passed over Belau on 11 March, then the sustained surface winds increased to 30 kt (15 m/sec) as Sharon moved west of the station. Later, as the tropical cyclone continued to weaken over the central Philippine Islands, JTWC issued the final warning at 140000Z. The remnants of Sharon continued westward across the South China Sea and dissipated over southeastern Vietnam on 16 March.


TYPHOON TIM
BEST TRACK TC-02W
18 MAR- 29 MAR 91
MAX SFC WIND 70KT
MINIMUM SLP 972MB
E 135
140
145
150
155
160
165
170
175
180
N 35
30
25
20
15
10
5
EQ
L - 25/18Z
F - 21/00Z
TCFA
ABPW
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TYPHOON TIM (02W)

I. HIGHLIGHTS

Tim was the second tropical cyclone to develop in the eastern Caroline Islands during the month of March. It was the first March typhoon since 1982, and marked only the third time since the Joint Typhoon Warning Center was established in 1959 that multiple storms occurred in March. The recurvature track taken by Tim proved to be a difficult challenge for JTWC forecasters to predict, because the primary prognostic guidance was slow to predict the changing synoptic situation. Average forecast errors for Tim were the largest of any Northwest Pacific tropical cyclone forecast in 1991.

II. TRACK AND INTENSITY

As the Southern Hemisphere Tropical Cyclone, 16P (Cynthia), intensified in the Coral Sea on 18 March, analysis of the surface and gradient-level wind flow in the tropics indicated that a westerly surge was again established along the equator east of New Guinea. Just two weeks after Sharon (01W) formed in the eastern Caroline Islands, the near-equatorial trough reestablished itself in the same area with associated pressure falls and increased cloudiness. The first mention of a developing tropical disturbance (Tim) appeared on the 18 March Significant Tropical Weather Advisory. Later, based on a 38 kt (20 m/sec) gradient-level wind at Pohnpei (WMO 91348) and a 2-day pressure fall of 2 to 3 mb, a Tropical Cyclone Formation Alert was issued at 200500Z. The first warning on Tropical Depression 02W followed at 210000Z when satellite imagery located a poorly defined cloud vortex that was aligned with the synoptic data.

As it tracked northwestward, Tim was upgraded to a tropical storm at 211800Z due to an increase in the amount of deep convection. The track became more northerly as a series of fast-moving short waves in the polar westerlies eroded the narrow subtropical ridge, allowing Tim to move towards the break in the ridge. At 230600Z, typhoon intensity was attained when Tim developed a large, ragged eye (Figure 3-02-1). Tim arrived at its point of recurvature 420 nm (780 km) east of Saipan. Twelve hours after recurvature, the typhoon reached a peak intensity of 70 kt (35 m/sec) and then began to weaken gradually due to increased vertical shear. Tim transitioned to an extratropical low on 25 March.

III. FORECAST PERFORMANCE

JTWC's larger than average overall forecast errors on this typhoon were a consequence of over-reliance on guidance from its primary aids (Figure 3-02-2) which weren't representative of the changing synoptic situation. Initially, the majority of JTWC's forecast aids indicated Tim would move along a climatologically favored west-northwestward track, steered by the flow south of the narrow subtropical ridge. Post-analysis of the synoptic situation showed that Typhoon Tim tracked north-northwestward into a neutral point in the subtropical ridge located east of Saipan. This neutral point was identified in the 200000Z NOGAPS prognostic series used to develop the first warning, but based on the depiction of the forecast aids, recurvature was not considered a likely scenario. Recurvature was discussed as a moderate probability alternate scenario on JTWC's first warning, but when the dynamic aids OTCM and FBAM continued to indicate Tim would turn to the west and remain south of the ridge axis, the recurvature philosophy was discarded in favor of a "stairstep" track which agreed more closely with the prognostic aids. Supporting NOGAPS prognostic fields indicated the portion of the subtropical ridge east of the neutral point would build westward (and to the north of the cyclone) and cause Tim to continue moving northwestward. JTWC warnings reflected this forecast reasoning, and as a result,

failed to identify in the early stages of development that Tim's more northward motion was a precursor to recurvature. In particular, JTWC's overall best performing forecast aid, OTCM, missed the recurvature point entirely.

Typhoon Tim intensified at a normal rate of development, and its intensification and extratropical transition were well forecast by JTWC.

IV. IMPACT

No reports of significant damage or loss of life were received as Tim remained over open ocean well away from land during its life.

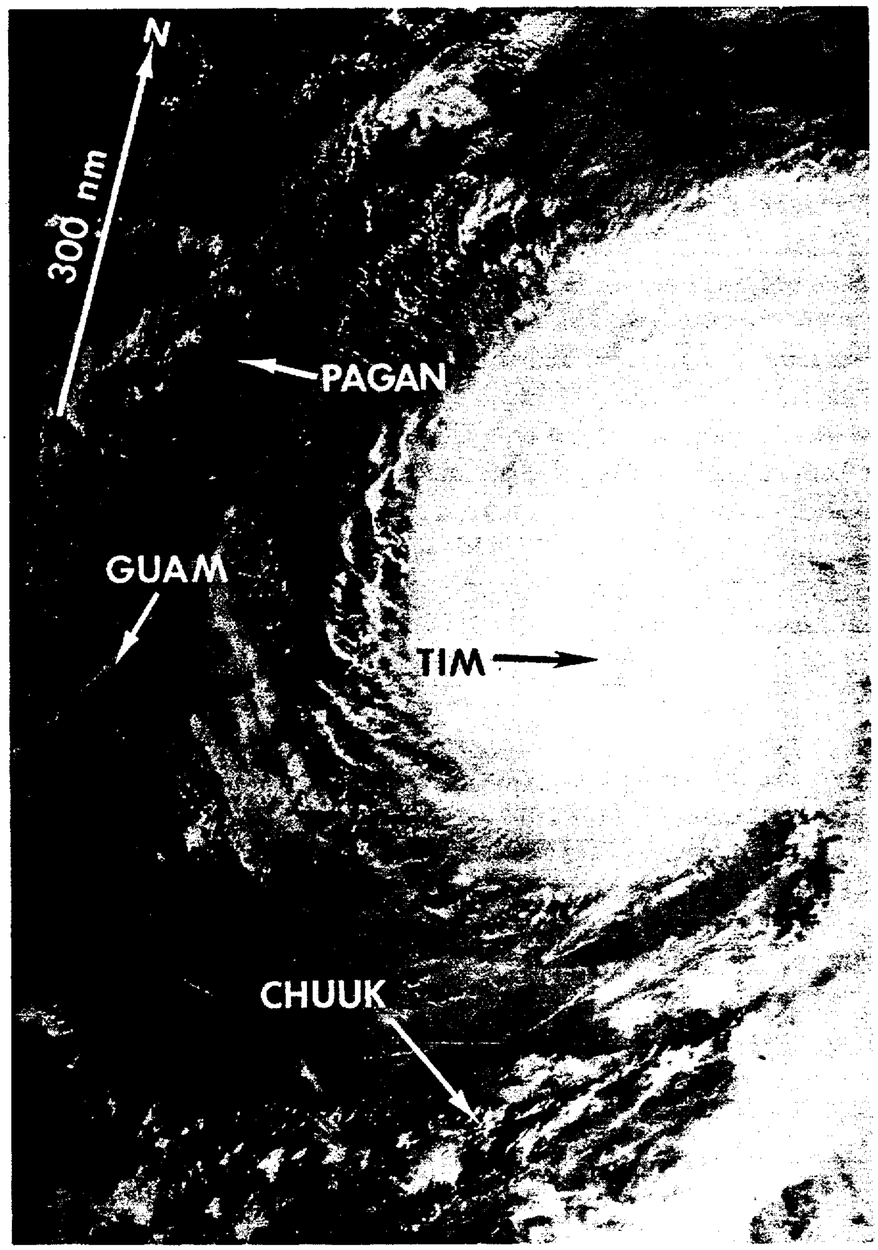


Figure 3-02-1. Satellite imagery of the large, cloud-filled eye of Typhoon Tim approximately 12 hours prior to reaching maximum intensity (230431Z March NOAA visual imagery).

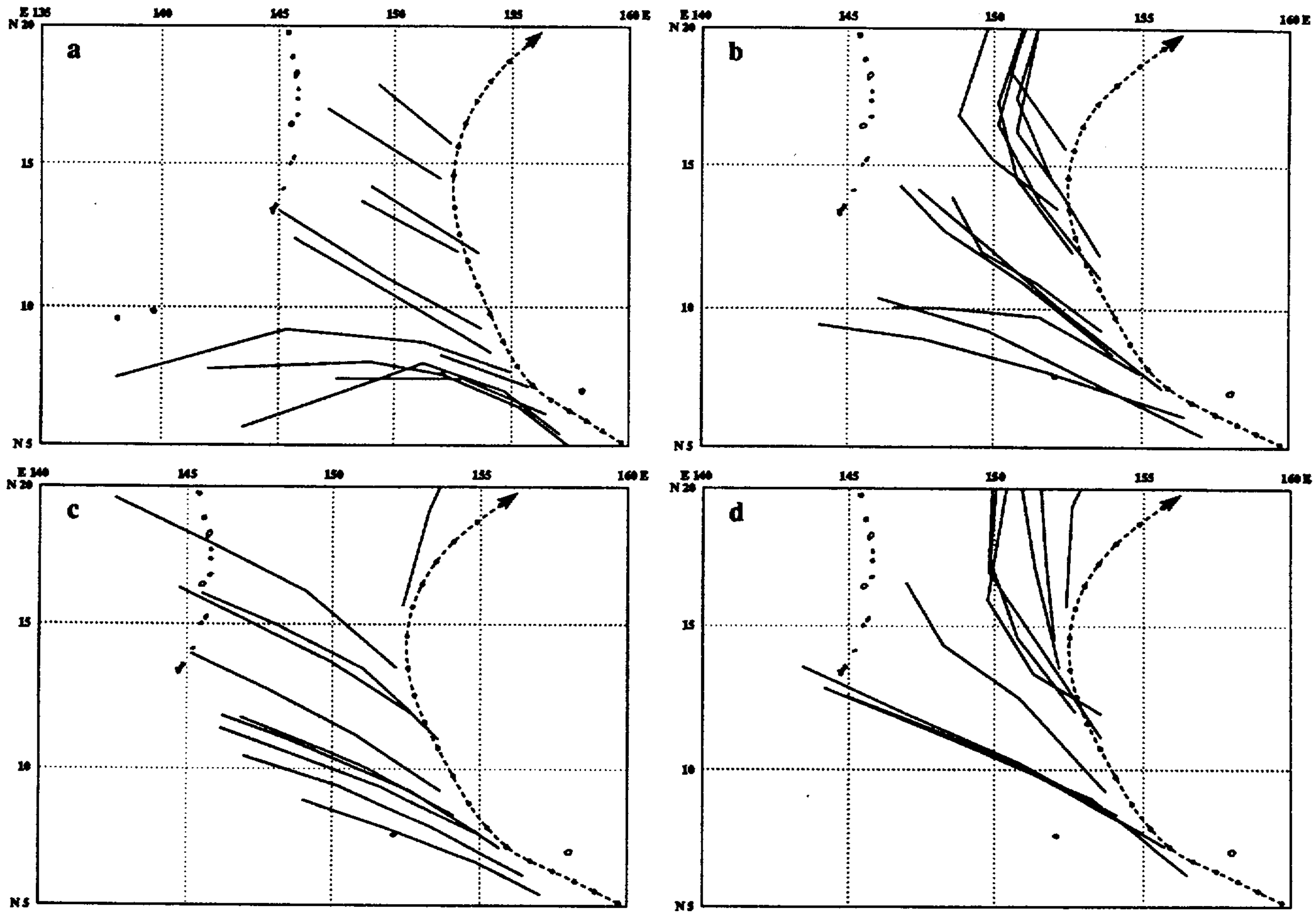
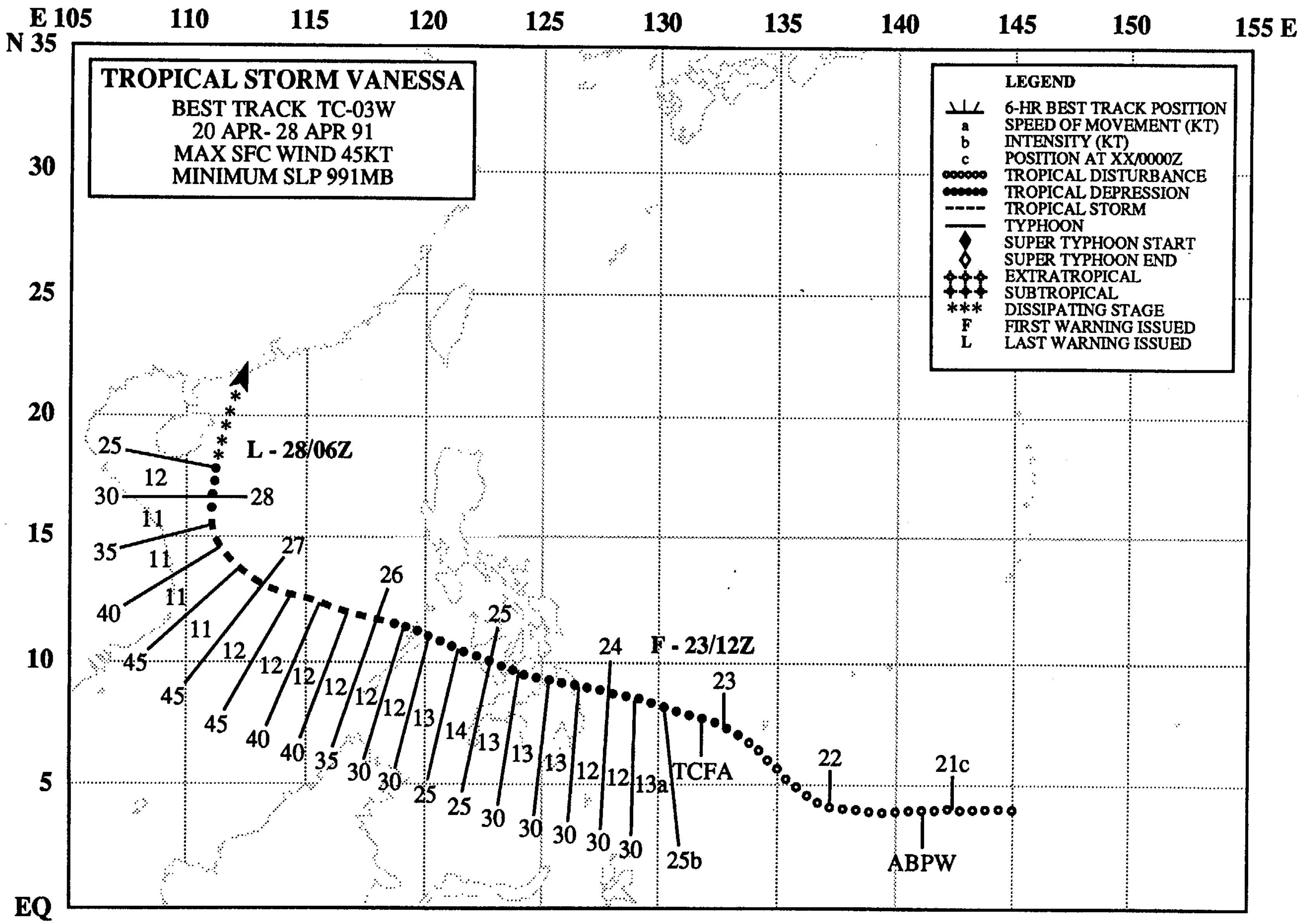


Figure 3-02-2. JTWC's primary forecast aids [a) OTCM, b) FBAM, and c) the CSUM] remained consistently left of track. While the official JTWC forecasts [d) JTWC] were consistently to the right of the other aids, in retrospect, they were not far enough to the right.


TROPICAL STORM VANESSA
BEST TRACK TC-03W
20 APR- 28 APR 91
MAX SFC WIND 45KT
MINIMUM SLP 991MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 105
110
115
120
125
130
135
140
145
150
155 E
N 35
30
25
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EQ
L - 28/06Z
F - 23/12Z
TCFA
ABPW
13a
25b
21c

TROPICAL STORM VANESSA (03W)

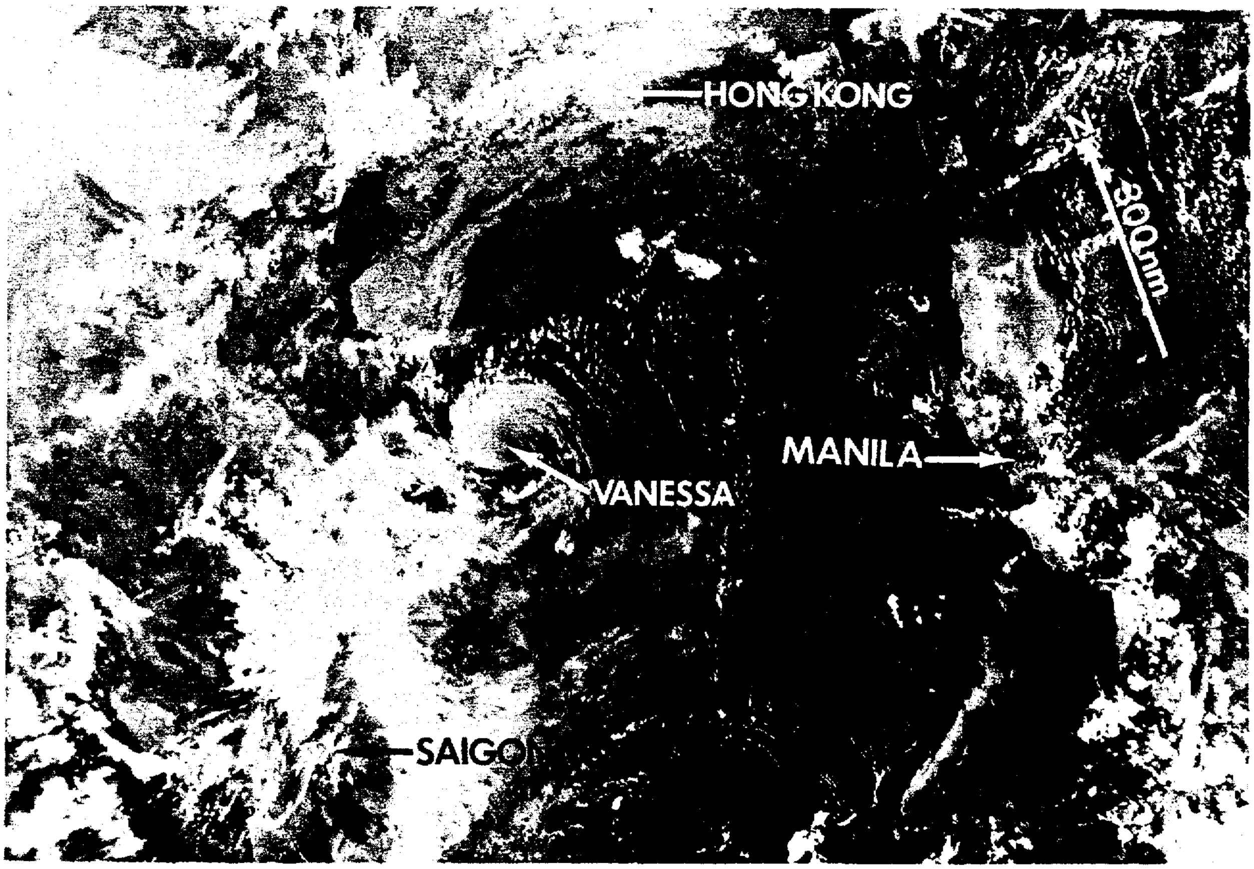
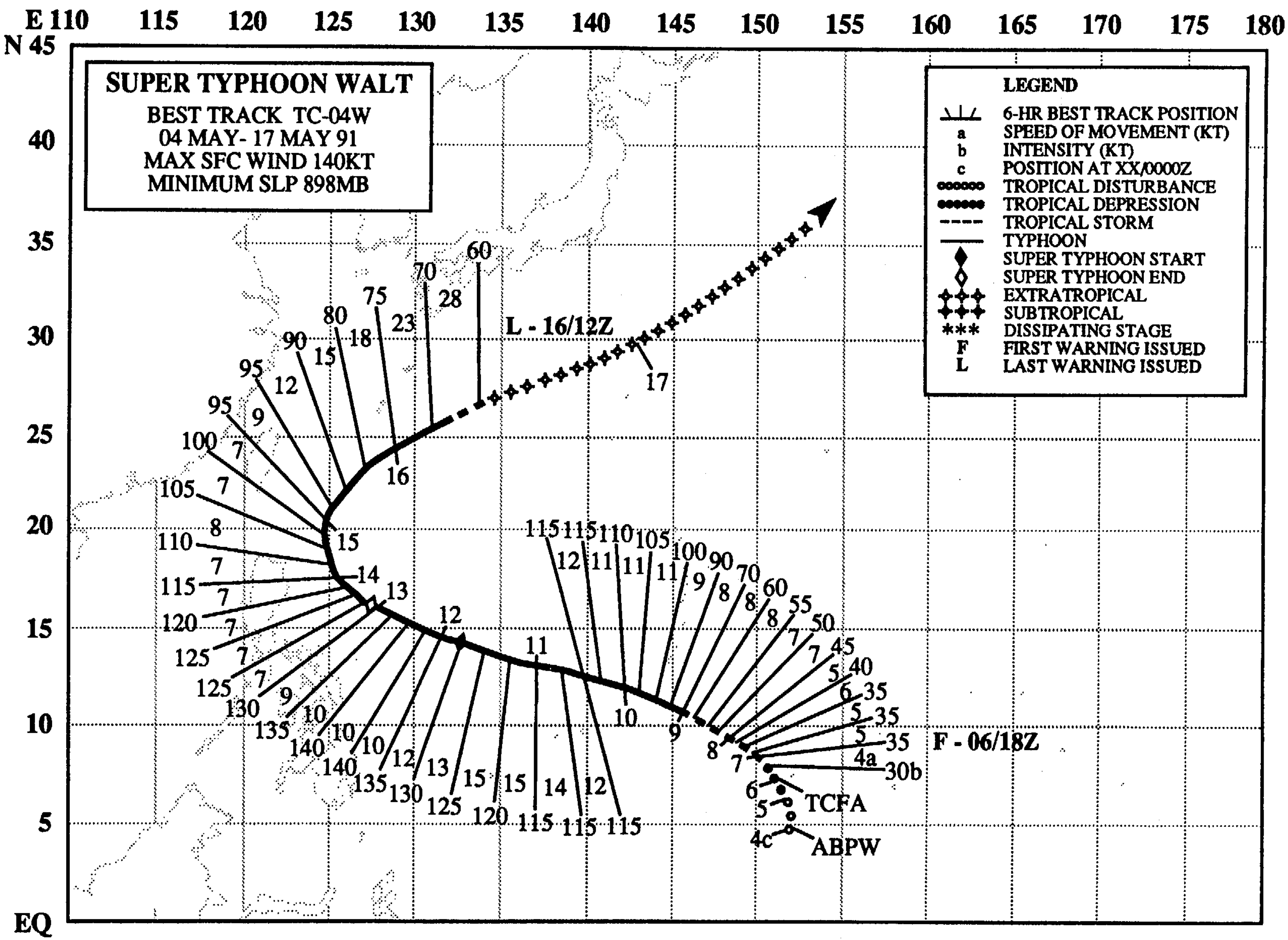


Figure 3-03-1 The exposed low-level center of Tropical Storm Vanessa approaches the coast of Vietnam (271905Z NOAA April enhanced infrared imagery).

After Typhoon Tim (02W) in mid-March, the near-equatorial trough remained relatively inactive until Vanessa's convection flared up to the south of Guam over a month later. This disturbance with its persistent convection was first mentioned in the Significant Tropical Weather Advisory on 21 April. A Tropical Cyclone Formation Alert was issued at 230500Z when animated satellite imagery revealed that individual thunderstorms had started rotating cyclonically about a singular point. At 231200Z, the alert was followed by the first warning on Tropical Depression 03W, based on a 30 kt (15 m/sec) ship report. Vanessa did not intensify as it tracked south of the subtropical ridge and across the central Philippines. Twenty-four hours after leaving the Philippine Islands, it reached tropical storm intensity at 260000Z, based on a satellite intensity estimate of 35 kt (18 m/sec). Vanessa peaked at 45 kt (23 m/sec) in the South China Sea at 261800Z. Less than a day later, vertical wind shear caused Tropical Storm Vanessa to weaken rapidly. Satellite imagery showed that Vanessa had completely lost its deep central convection. This prompted the JTWC to issue its final warning at 280600Z. Embedded in the prevailing low-level flow, the remnants of Tropical Storm Vanessa moved northward through the axis of the subtropical ridge, and dissipated southwest of Hong Kong.


SUPER TYPHOON WALT
BEST TRACK TC-04W
04 MAY- 17 MAY 91
MAX SFC WIND 140KT
MINIMUM SLP 898MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L - 16/12Z
F - 06/18Z
TCFA
ABPW
E 110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
N 45
40
35
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25
20
15
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5
EQ

SUPER TYPHOON WALT (04W)

I. HIGHLIGHTS

Walt was the first super typhoon in the western North Pacific this year and the only significant tropical cyclone to form in May. It developed as part of an equatorial convective process known as a "westerly burst" (Lander, 1990) at the same time a twin, Tropical Cyclone 21P (Lisa), developed in the Southern Hemisphere.

II. TRACK AND INTENSITY

The cloud system that was to become Walt developed in low latitudes in the eastern Caroline Islands in tandem with Tropical Cyclone 21P (Lisa) in the Southern Hemisphere in the Coral Sea. The evolution of these twins is graphically portrayed as cloud silhouettes in Figure 3-04-1. The tropical disturbance initially tracked northwestward towards a weakness in the subtropical ridge north of Guam. However, the subtropical ridge strengthened, built westward, and forced Walt to take a more west-northwesterly track. The tropical cyclone kept on this course for ten days until recurvature occurred early on 15 May. Then, Walt interacted with the polar westerlies aloft and accelerated east-northeastward. Extratropical transition occurred on 16 May as Walt merged with a passing frontal system.

In review, the persistence of Walt's convection prompted first mention on the Significant Tropical Weather Advisory at 040600Z. At 060200Z, a Tropical Cyclone Formation Alert followed the report of a 23 kt (12 m/sec) gradient-level wind at Chuuk (WMO 91334) and a 30 kt (15 m/sec) ship report. Cyclonic rotation of the convective cloud elements on the animated satellite imagery and 20-30 kt (10-15 m/sec) synoptic reports resulted in the issuance of the first warning at 061800Z. The upgrade to tropical storm intensity at 070000Z resulted from a Dvorak intensity estimate increase and another 30 kt (15 m/sec) ship report. A typhoon intensity estimate resulting from the appearance of a ragged eye prompted a warning upgrade to typhoon at 090000Z. Intensification continued, reaching a peak of 140 kt (70 m/sec) at 120600Z. As Walt approached the axis of the subtropical ridge, the vertical shear increased and the typhoon's cloud shield elongated southwest to northeast (Figure 3-04-2). Slow weakening set in and continued through extratropical transition which occurred at 161800Z.

III. FORECAST PERFORMANCE

The overall track errors were 70 nm (130 km), 150 nm (275 km) and 225 nm (420 km) for the 24-, 48-, and 72-hour forecast, respectively. OTCM, CSUM and NOGAPS also did well and demonstrated skill in comparison with CLIPER.

The intensity forecasts were not as skillful. Although rapid intensification and peaking at super typhoon intensity were discussed early in the prognostic reasoning messages, it remained an alternate scenario. However, once rapid intensification began, JTWC did do a much better job of forecasting peak intensity and the weakening trend. Accurate forecasts near Guam prevented DOD and the Government of Guam from taking expensive unnecessary precautions saving upwards of US$3 million.

IV. IMPACT

Even though Walt passed near Guam, northern Luzon and Okinawa, no reports of significant damage were received.

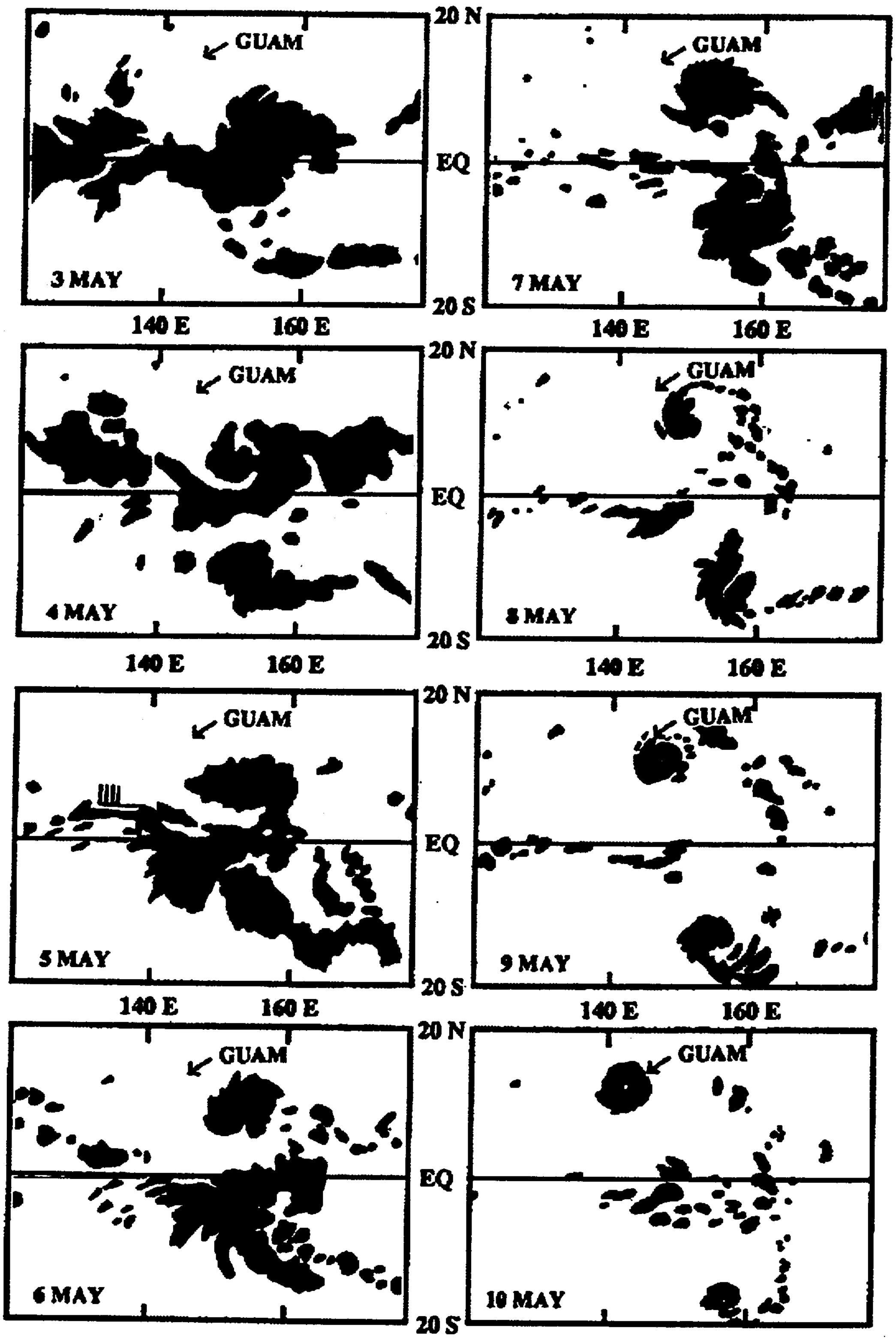


Figure 3-04-1. Silhouettes of deep cloudiness are associated with the "westerly burst" for the period 03 to 10 May. A 40 kt (20 m/sec) ship report, which also cited blowing spray, near the equator on 05 May is unusually strong. As the equatorial convection and westerlies decrease on 7 May, the cloudiness consolidates in the twin cyclones in opposite hemispheres.

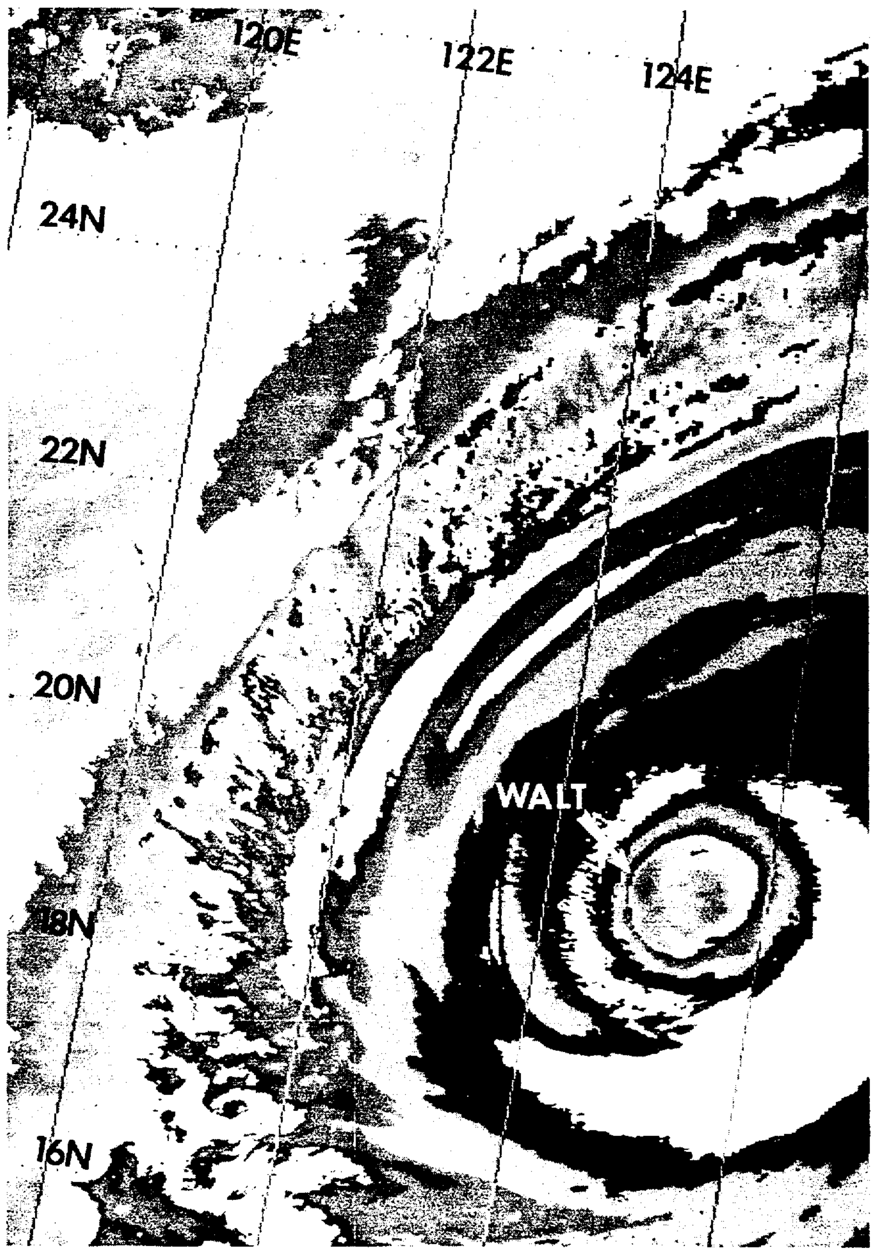
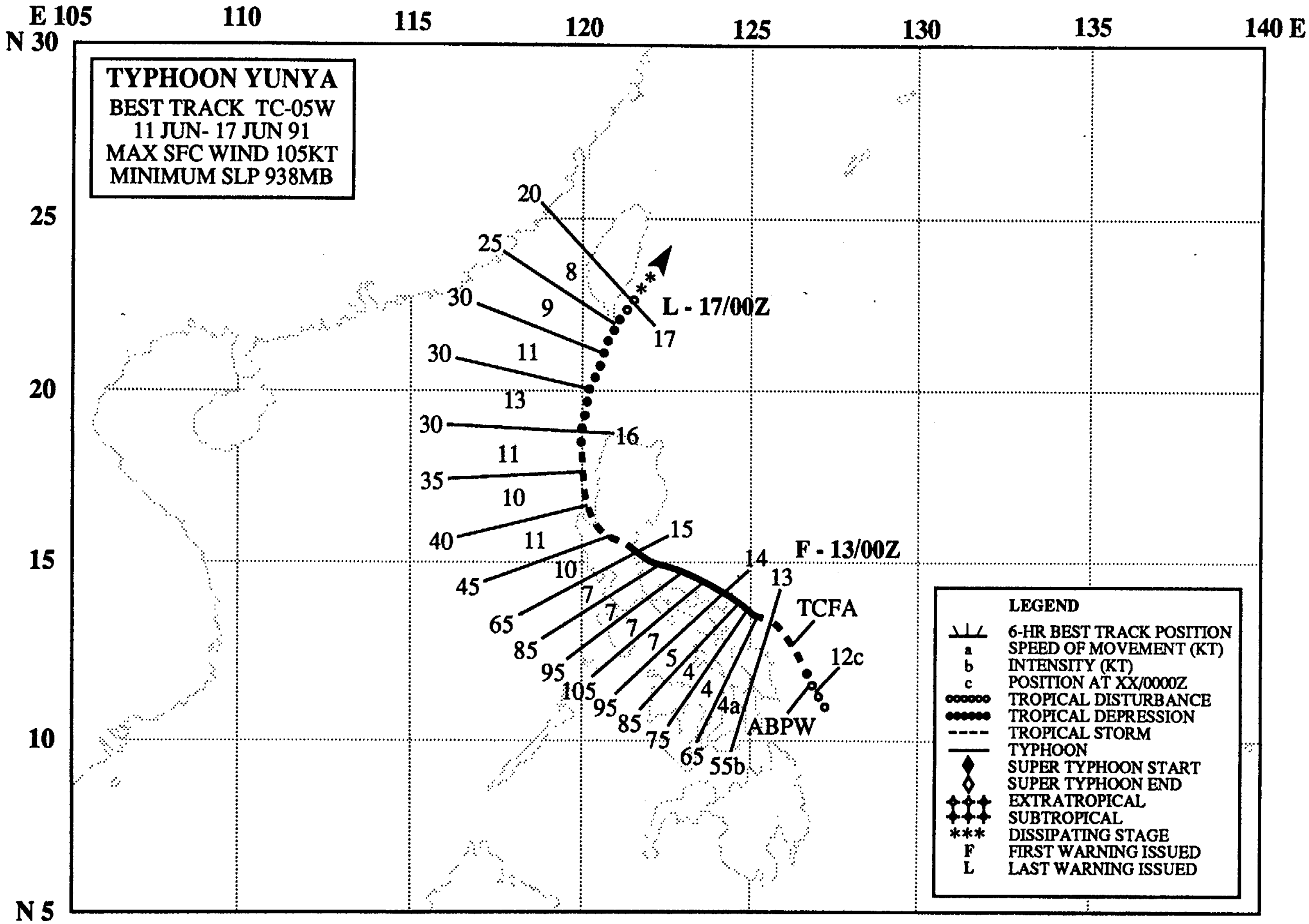


Figure 3-04-2. Walt shows first indications of vertical shear on system forcing the overall elongation of the cloud shield along an axis from southwest to northeast (141120Z May NOAA enhanced infrared imagery).


TYPHOON YUNYA
BEST TRACK TC-05W
11 JUN- 17 JUN 91
MAX SFC WIND 105KT
MINIMUM SLP 938MB
L - 17/00Z
F - 13/00Z
TCFA
ABPW
LEGEND
6-HR BEST TRACK POSITION
SPEED OF MOVEMENT (KT)
INTENSITY (KT)
POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED

TYPHOON YUNYA (05W)

I. HIGHLIGHTS

Typhoon Yunya, the first significant tropical cyclone of June, broke a nearly month-long lull in activity in the western North Pacific. Yunya was noteworthy because a ship transited through its center, providing a unique glimpse of the structure of a rapidly-developing midget typhoon. Its passage through central Luzon coincided with the massive eruption of Mount Pinatubo and subsequent evacuation of personnel from Clark AB.

II. TRACK AND INTENSITY

Yunya formed just east of Samar Island, Republic of the Philippines, in an area of low vertical wind shear associated with a col produced by a Tropical Upper Tropospheric Trough (TUTT). Unlike normal TUTT-induced tropical cyclone genesis which occurs in the region of strong upper-level divergence between the TUTT and the sub-equatorial ridge circulation to the southeast, Yunya's formation occurred southwest of the TUTT axis.

The broad disturbance which spawned Yunya was first discussed on the 110600Z Significant Tropical Weather Advisory. Between 111200Z and 121200Z, all surface reports within 100 nm (185 km) of the low-level circulation were less than 10 kt (5 m/sec). After a Tropical Cyclone Formation Alert was issued at 121500Z, the system began to rapidly develop. At 121730Z, a satellite analysis based on spiral band curvature estimated a maximum intensity of 30 kt (15 m/sec). Post analysis revealed a tiny central dense overcast (CDO) supporting 45 kt (23 m/sec). Then, at 121836Z the **USNS Spica** passed through the center of the system, and reported a central pressure of 989.5 mb with winds of 60 kt (30 m/sec). At 130000Z, JTWC issued its first warning on Yunya with an intensity of 45 kt (23 m/sec) was based on a conversion from observed minimum sea-level pressure to maximum sustained surface wind using the Atkinson-Holliday (1977) relationship. Post analysis determined the actual intensity was closer to 55 kt (28 m/sec).

Yunya reached minimal tropical storm intensity after existing for only 21 hours and minimal typhoon intensity in only 39 hours. In so doing, it did not exhibit the classic tropical cyclone development traits, but those of rapid initial development, small surface wind field, and peripheral surface pressure rises presumably associated with subsidence generated by a tiny annular outflow pattern aloft. These traits are found to be common with "midget typhoon" development. The fortuitous (for meteorologists) passage of the **USNS Spica** near the center of Yunya confirmed its midget size via the pressure trace shown in Figure 3-05-1. The wind observations reported by **Spica** indicate that the

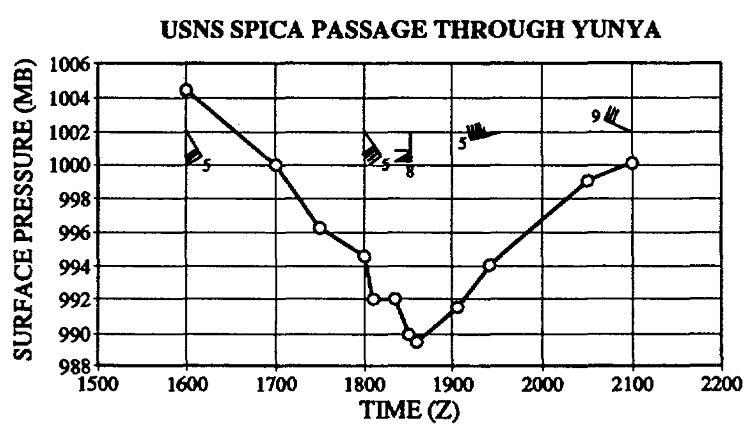


Figure 3-05-1. Time pressure cross-section reconstructed from data provided by the USNS Spica, which passed directly through the center of Yunya on the 12 of June.

area of winds greater than 30 kt (15 m/sec) was transited in a mere 5 hours. Since **Spica's** course and speed were reported as 286 degrees true at 16 kt (30 km/hr) for the duration of the transit, the associated 30 kt (15 m/sec) wind diameter for Yunya at this time was about 80 nm (150 km).

After moving northwestward for a day during its formation phase, Yunya then tracked west-northwestward toward central Luzon under the influence of the mid-level subtropical ridge. Yunya steadily intensified at a rate of 10 kt (5 m/sec) per 6 hours until 140600Z when it attained its peak intensity of 105 kt (55 m/sec) (Figure 3-05-2). Subsequently, strong north-northeasterly upper-level winds associated with an eastward building of the subtropical ridge circulation over Asia produced unfavorable vertical wind shear. As this shear (Figure 3-05-3) persisted, Yunya began to weaken even faster than it had intensified, having only minimal typhoon intensity as it made landfall just north of Dingalan Bay at 150000Z. Apparently, the midget size of the typhoon could not effectively buffer its core of convection from the shear. Yunya exited Luzon though the Lingayen Gulf as a weak tropical storm, and subsequently turned north toward a break in the subtropical ridge. The system continued to weaken due to strong vertical wind shear, grazing the southern tip of Taiwan as a tropical depression, and dissipating before it could complete full recurvature into the mid-latitude westerlies.

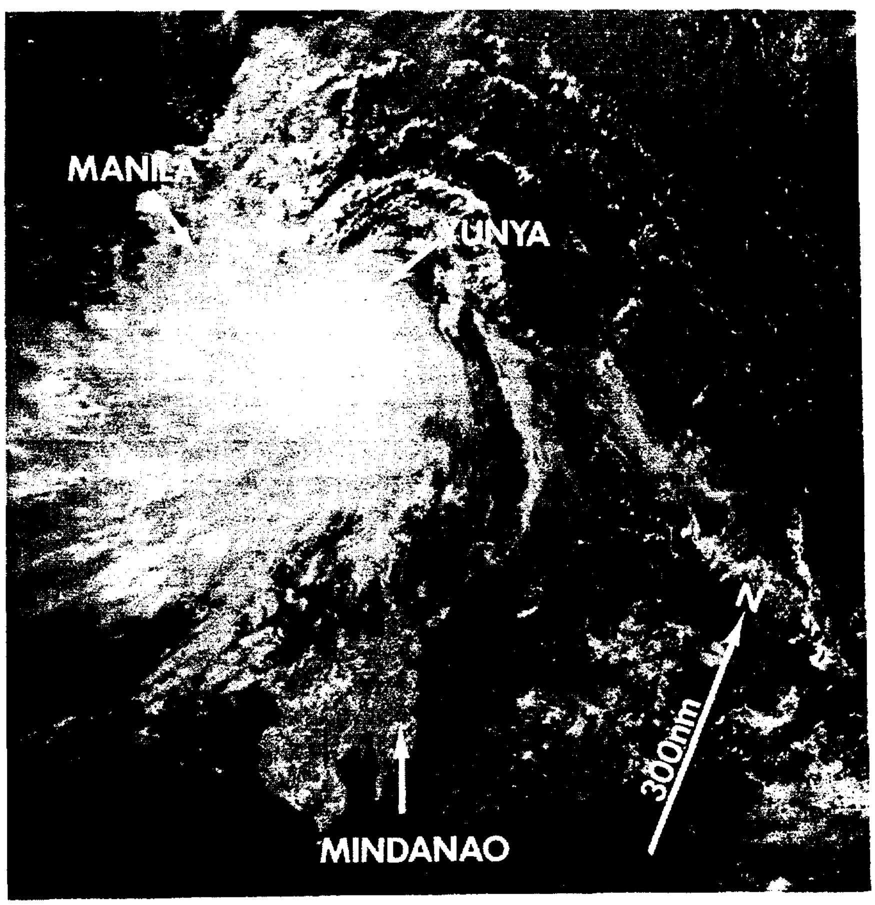


Figure 3-05-2. Yunya at peak intensity. Note the distortion of Yunya's cloud signature due to increasing upper-level north-northeasterly winds produced by a building subtropical ridge (140534Z June NOAA visual imagery).

III. FORECAST PERFORMANCE

The first two track forecasts issued by JTWC had Yunya moving in a northwestward direction toward a thin extension of the mid-level subtropical ridge, eventually grazing the northeast tip of Luzon (Figure 3-05-4). By the third warning however, JTWC correctly anticipated that Yunya's midget size

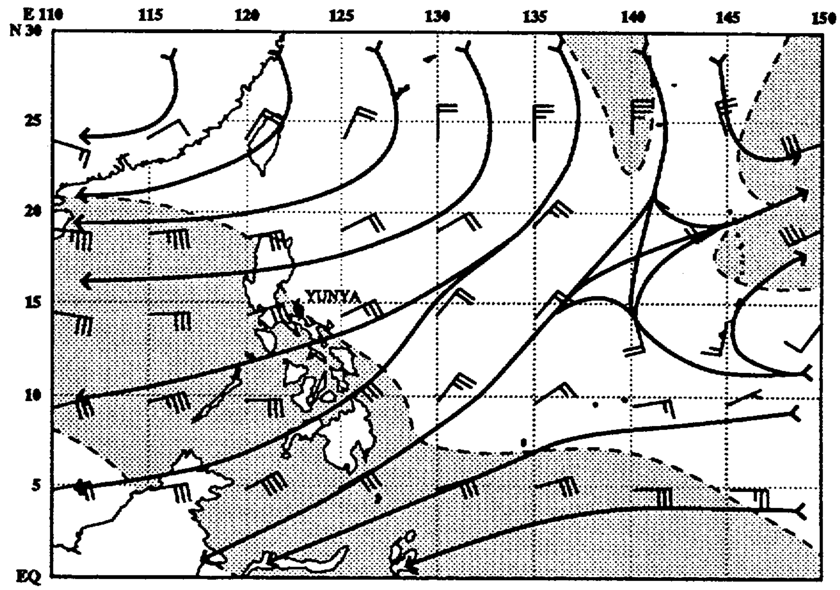


Figure 3-05-3. NOGAPS 200-mb analysis at 150000Z June showing an increased upper-level shear over Yunya. The JTWC hand-plotted/analyzed chart for this same this showed up to 40 kt (20 m/sec) 200-mb winds in the vicinity of Yunya. (Winds within the shaded area of the analysis are 30 kt (15 m/sec) or greater.)

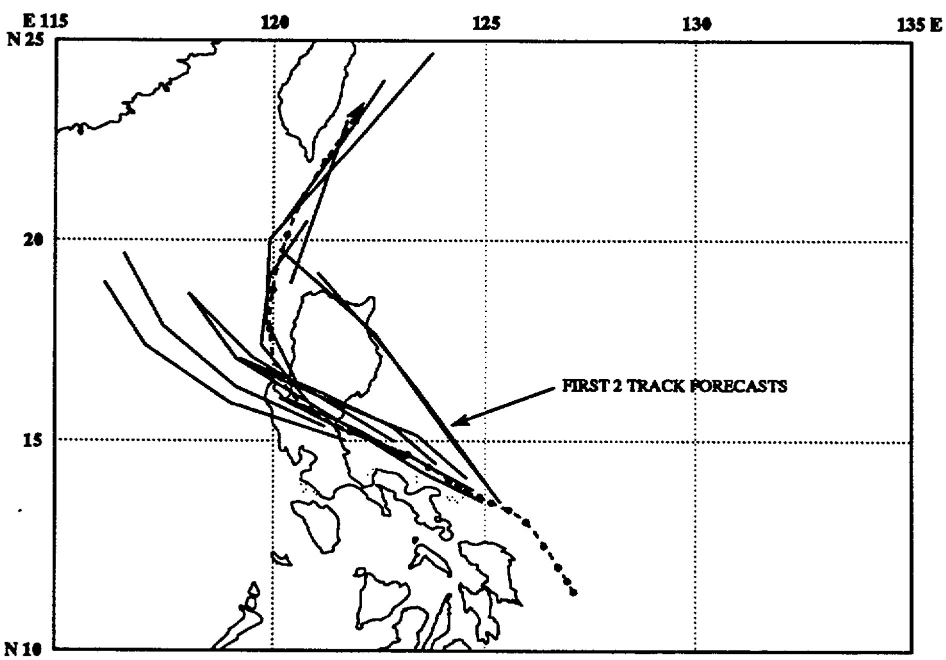


Figure 3-05-4. Graphic of all JTWC official forecasts issued for Yunya.

would prevent significant penetration into the thin ridge, and that Yunya would instead be steered around the periphery of the ridge, resulting in a track across central Luzon. After Yunya crossed Luzon, it turned toward the ridge axis sooner than anticipated, highlighting the sensitive and subtle interplay between tropical cyclone and weak ridge near the point of recurvature.

Figure 3-05-5 shows the objective forecast guidance that JTWC used to develop the 140000Z forecast, and Figure 3-05-6 shows the 48-hour NOGAPS 700-mb prognostic field associated with the mid-point of the 72-hour forecast period beginning at 140000Z. From these figures, it is evident that JTWC had to discount the track forecasts by the dynamical models NGPS and OTCM which tended to turn Yunya prematurely through the thin subtropical ridge. Forecasters placed more weight on climatology (CLIM), CSUM (statistical-dynamical) and FBAM (a steering-type dynamical aid) which provided better guidance, but which historically tend to be slow to forecast recurvature. It is interesting to note also that the Japanese Meteorological Agency Typhoon Model (JTYM) and the United Kingdom Meteorological Office Model (EGRR) also forecast Yunya through the thin ridge extension, suggesting that this problem is endemic to the current generation of vortex-tracking numerical models. With the midget typhoon, the model's inability to accurately describe the cyclone-ridge interaction may be a resolution problem.

Despite a slow speed bias, JTWC's forecasts of Yunya across Luzon provided key warning support which helped prompt DOD officials to evacuate the Clark and Subic areas in anticipation of the devastation to be caused by the Mount Pinatubo ash moistened and redirected by Yunya.

IV. IMPACT

Yunya made landfall in central Luzon near midday on 15 June, and the associated heavy rainfall caused flooding that washed away bridges and left one person dead. However, this direct impact of Yunya was relatively minimal compared to its subsequent influence on the massive cloud of ash produced by the eruption of Mount Pinatubo on the same day. As Yunya crossed central Luzon, its deep cyclonic circulation redistributed the ash, that normally would have been carried out over the South China Sea, over land. This greatly aggravated the impact of the water-laden ash fall-out on Clark AB and at the Subic Bay/Cubi Pt naval complex, resulting in the downing of power lines and the collapse of most flat-roofed buildings due to overloading.

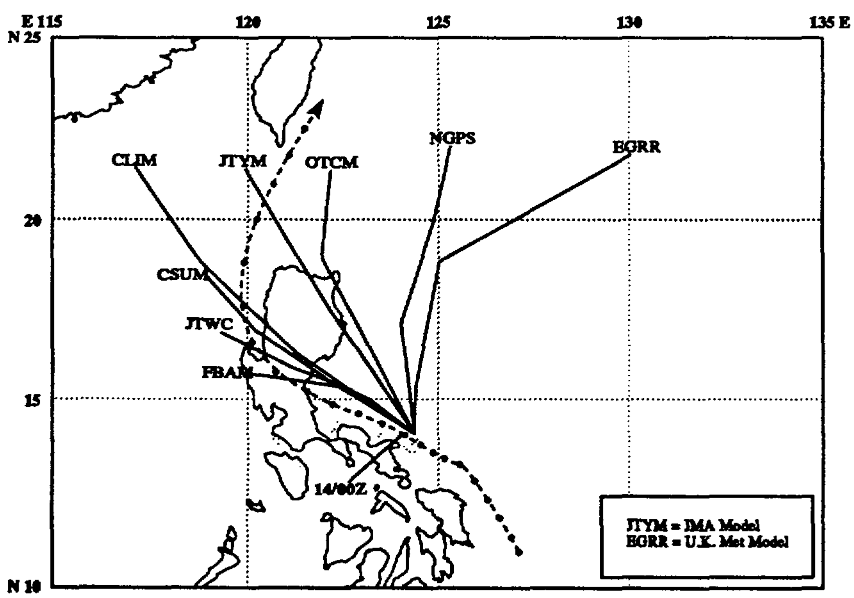


Figure 3-05-5. Graphic of JTWC official forecast and the associated objective forecast aids valid at 140000Z June.

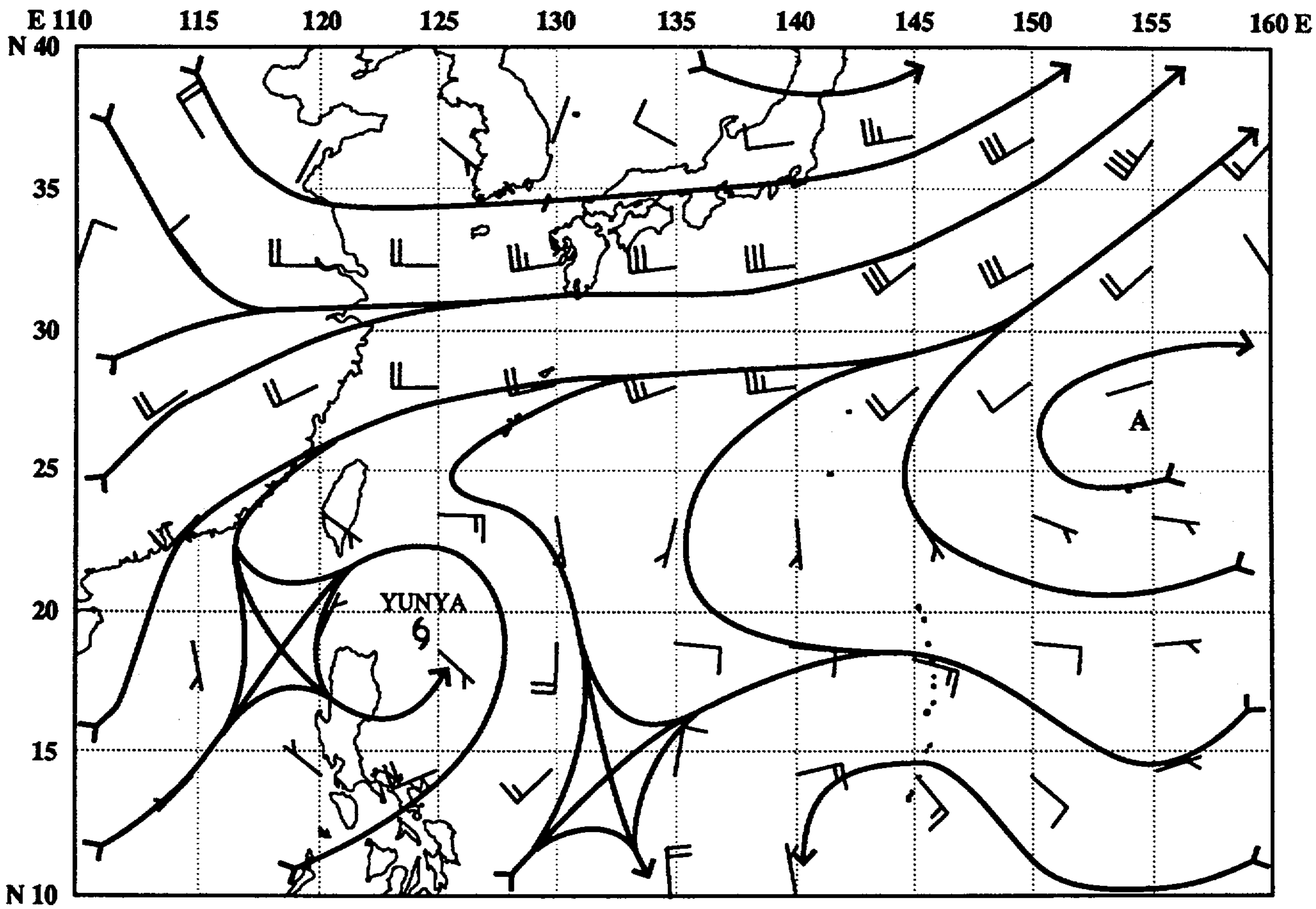
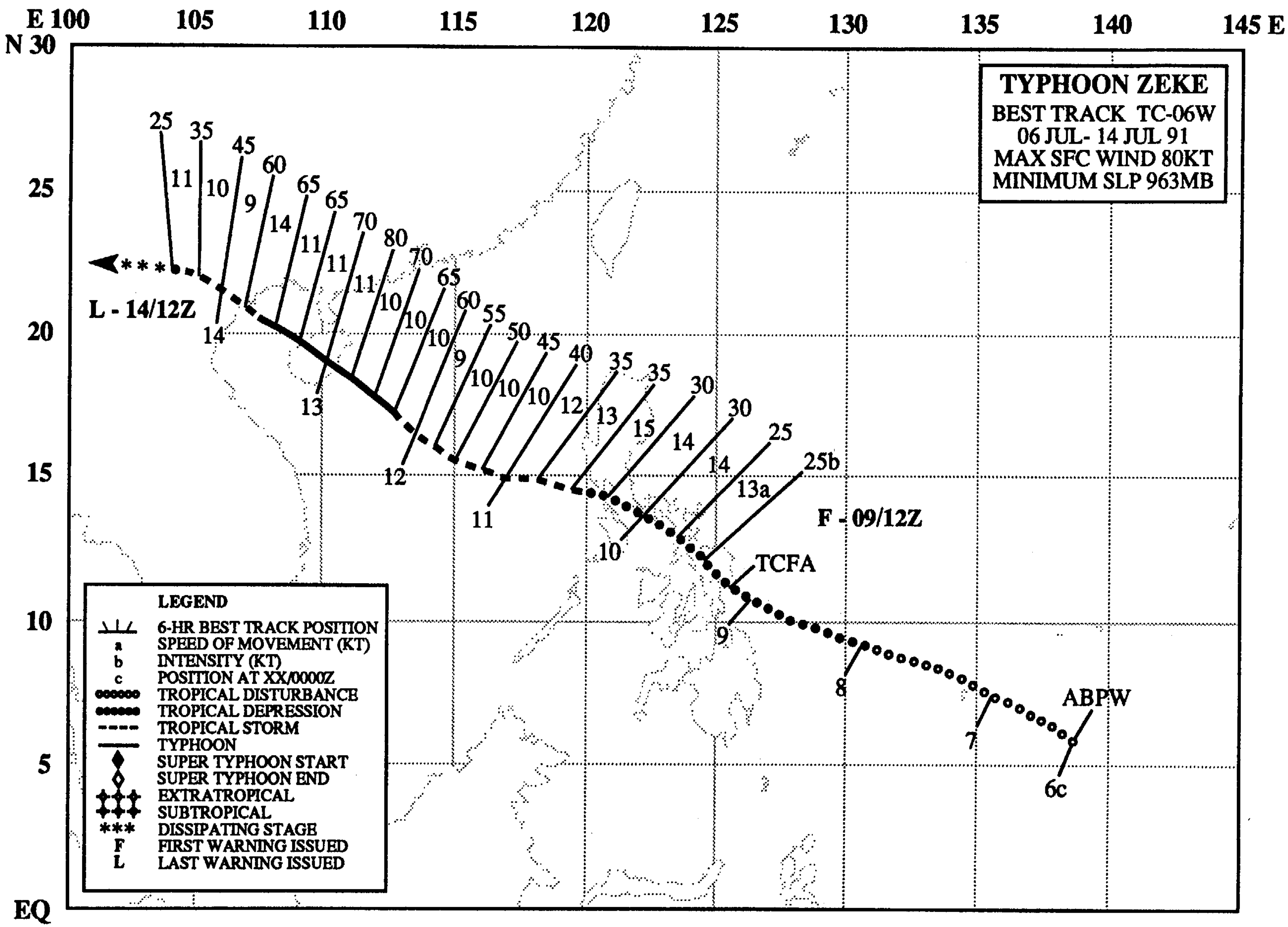


Figure 3-05-6. NOGAPS 700-mb 48-hour prognostic field valid at 151200Z, which is the midpoint of the forecast period beginning at 140000Z.


TYPHOON ZEKE
BEST TRACK TC-06W
06 JUL- 14 JUL 91
MAX SFC WIND 80KT
MINIMUM SLP 963MB
E 100
105
110
115
120
125
130
135
140
145 E
N 30
25
20
15
10
5
EQ
L - 14/12Z
F - 09/12Z
TCFA
ABPW
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TYPHOON ZEKE (06W)

I. HIGHLIGHTS

Starting in the Philippine Sea, Typhoon Zeke (06W) made landfall three times before it dissipated over the mountains of northern Vietnam. Zeke was the first tropical cyclone to develop during the month of July, and initiated a period of nearly continuous warning status on at least one tropical cyclone in the Northwest Pacific through early December.

II. TRACK AND INTENSITY

For the most part, the subtropical ridge provided the primary steering for Zeke's persistent track to the west-northwest. The slight northward jog across the Philippine Islands from the basic track appears related to a surge in the southwesterly monsoonal flow over the South China Sea.

Zeke developed from a tropical disturbance in the monsoon trough southwest of Guam. Increased convection associated with the disturbance was first mentioned on the 060600Z Significant Tropical Weather Advisory. When the cyclonic circulation became evident on animated satellite imagery, a Tropical Cyclone Formation Alert was issued at 090400Z. The first warning on Tropical Depression 06W followed at 091200Z as the deep convection steadily increased around the cyclone's center. Zeke crossed the Republic of the Philippines as a depression and was upgraded to a tropical storm once it moved over open water in the South China Sea on 10 July. Synoptic reports from ships in the South China Sea revealed a highly asymmetric wind distribution around the cyclone center. The radius of 30 kt (15 m/sec) winds extended over 250 nm (465 km) southeast of the center, but less than 100 nm (185 km) to the northwest. This asymmetry appeared related to an adjustment of the monsoon southwesterlies due to the presence of the tropical cyclone, producing a cyclone structure similar to a large monsoon depression. Zeke reached its maximum intensity of 80 kt (40 m/sec) shortly before making landfall on Hainan Dao, but weakened very little crossing the island (Figure 3-06-1). It struck the coast of northern Vietnam, passing close to Hanoi. The final warning was issued at 141200Z as Zeke dissipated inland.

III. FORECAST PERFORMANCE

Although Zeke's final best track was nearly a straight line, the actual forecasts called for recurvature just east of Hainan Dao (Figure 3-06-2). Zeke was expected to turn northward near Hainan based on the NOGAPS prognostic series, which indicated that the subtropical ridge would break down near 110°E longitude. Rather than breaking down, the ridge north of the system strengthened and built westward as the long wave trough near 110°E retrograded allowing the high located near Okinawa to move westward towards Taiwan. Once forecasters recognized the adjustment of the ridge to the north, which prevented Zeke from moving directly northward, the forecasts reverted back to the straight-runner scenario.

IV. IMPACT

Despite passage close by the major population centers of Manila and Hanoi, Zeke's impact appeared to be negligible. No reports of significant damage were received, but damage to agriculture was probably high in Hainan Dao and northern Vietnam.

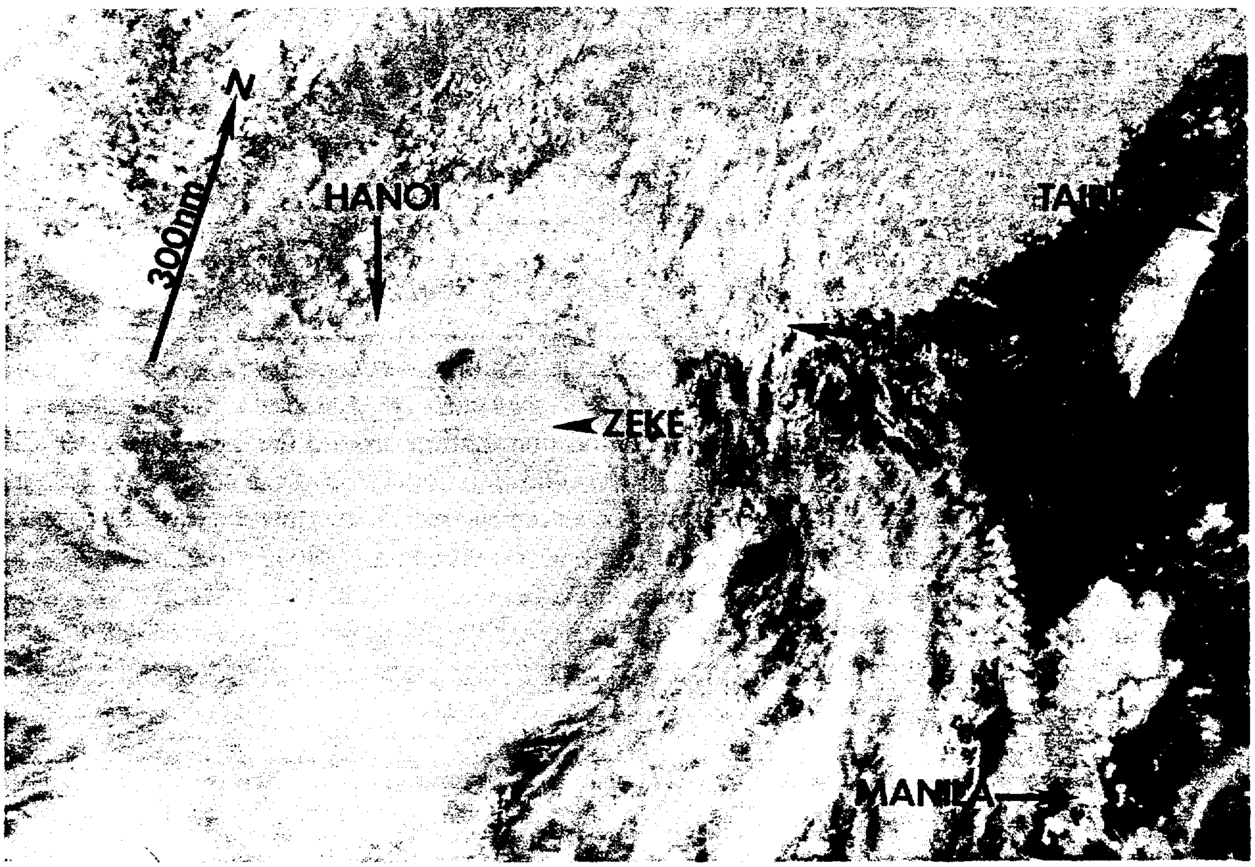


Figure 3-06-1. After crossing Hainan Dao, Typhoon Zeke retains 70 percent of its eyewall as it enters the Gulf of Tonkin (130644Z July NOAA visual imagery).

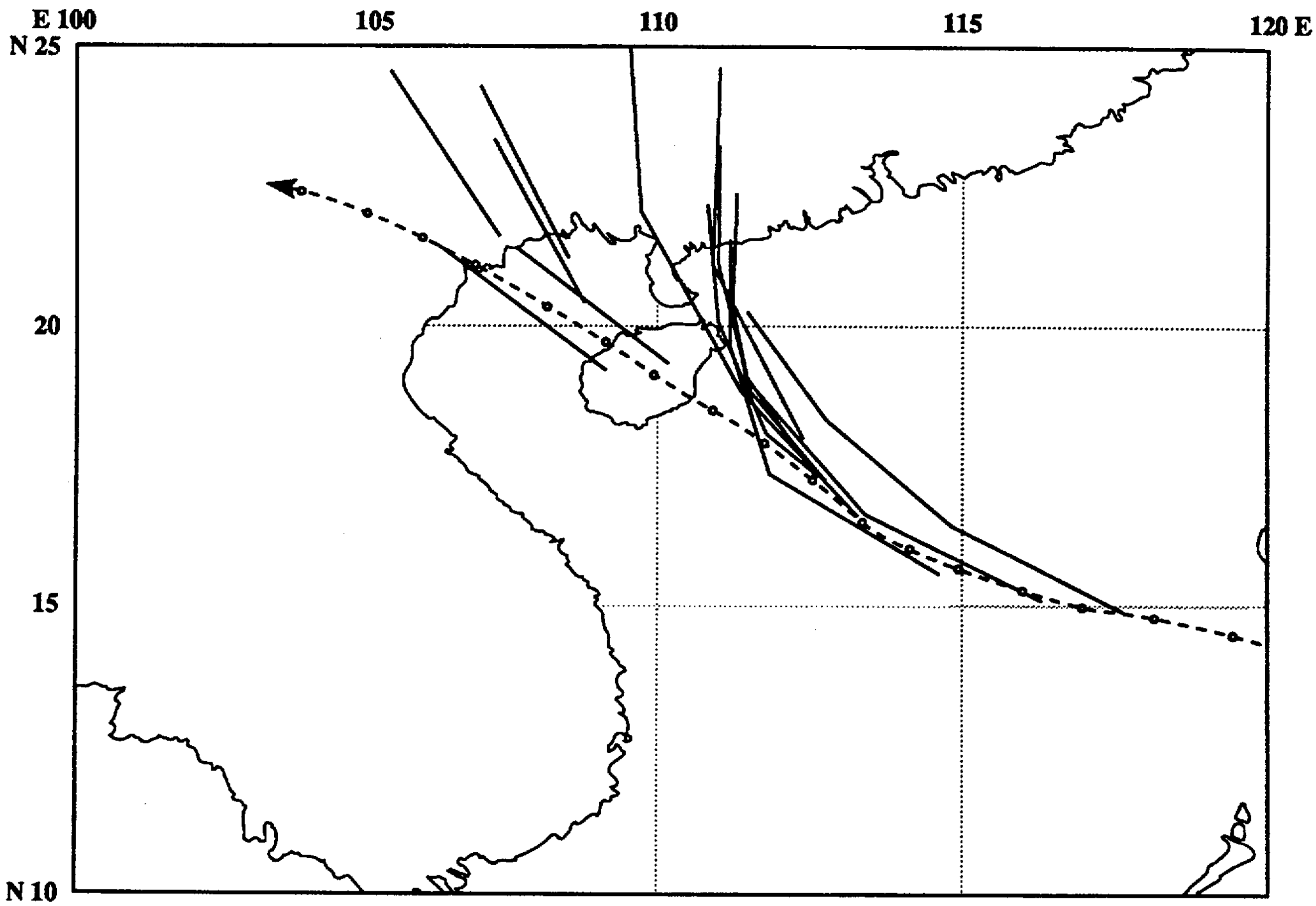
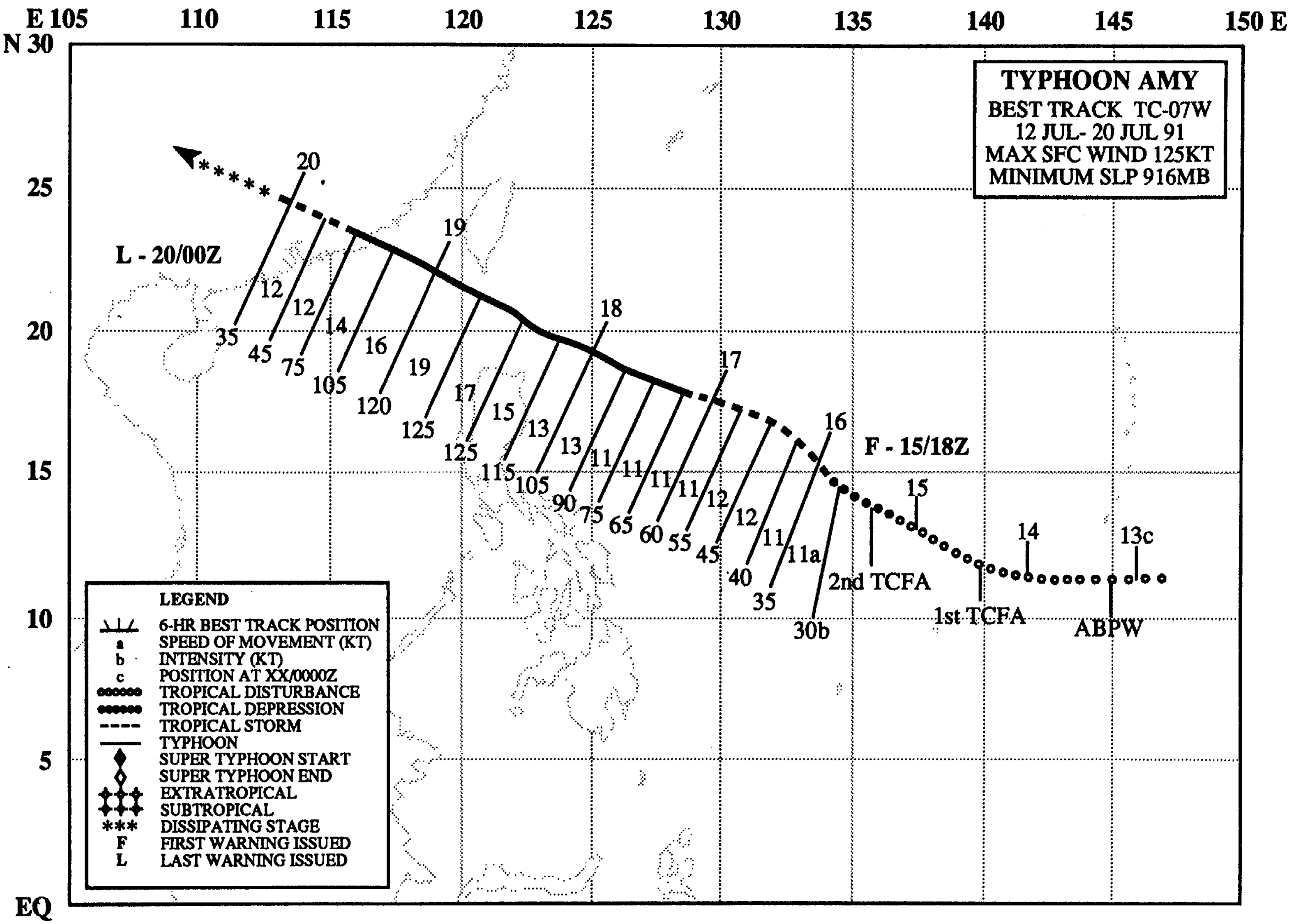


Figure 3-06-2. A comparison of JTWC forecasts issued after 101800Z July to the final best track. Recurvature was anticipated near 110°E longitude, but did not occur.


TYPHOON AMY
BEST TRACK TC-07W
12 JUL- 20 JUL 91
MAX SFC WIND 125KT
MINIMUM SLP 916MB
L - 20/00Z
F - 15/18Z
2nd TCFA
1st TCFA
ABPW
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 105
110
115
120
125
130
135
140
145
150 E
N 30
25
20
15
10
5
EQ

TYPHOON AMY (07W)

I. HIGHLIGHTS

The second of five tropical cyclones to form in July, Amy followed a west-northwesterly track that paralleled the one taken a week earlier by Typhoon Zeke (06W). Near Taiwan, the typhoon caused the loss of the freighter, **Blue River**, with its entire crew, and then became the deadliest typhoon to strike China this year.

II. TRACK AND INTENSITY

Amy, like typhoon Zeke (06W), took a straight-line west-northwestward track and remained south of the subtropical ridge axis. There was a small stair-step, or jog northwestward, on 16 July for about 18 hours as a mid-tropospheric shortwave trough passed by to the north. This shortwave temporarily weakened the ridge, and allowed Amy to gain latitude. Strong subsidence immediately behind the passing shortwave strengthened the subtropical ridge, once again producing a more easterly steering flow.

The tropical disturbance that became Amy was first mentioned in the Significant Tropical Weather Advisory at 130600Z after 18 hours of persistent convection. Increased convection, 2-mb pressure falls in a 24-hour period at Yap (WMO 91413), and the indication of little vertical wind shear led to the initial Tropical Cyclone Formation Alert at 141000Z. Although the overall cloud organization remained poor, deep convection persisted and a second alert followed at 151000Z. After the initial warning at 151800Z, Amy intensified at a rate of 5-10 kt (3 to 5 m/sec) every 6 hours. On the evening of 17 July, Amy began intensifying more rapidly, reaching a peak intensity of 125 kt (65 m/sec) in the Luzon Strait (Figure 3-07-1). The weakening trend began late on 18 July as the outflow became more restricted to the northwest and the typhoon approached the coast of mainland China (Figure 3-07-2). Upon making landfall, the system dissipated rapidly over the mountains in southeastern China. The final warning was issued at 200000Z.

III. FORECAST PERFORMANCE

Although the overall track forecast errors were below average there were some flaws: 1) the track acceleration in the Taiwan Straits was not anticipated or handled well by the dynamic models; 2) the forecast for the observed strong intensification was handled as a low probability alternate scenario until it actually was observed; and, 3) the unusual extension of gale and storm force winds far to the northeast of the typhoon was not anticipated. For example, Amy was at peak intensity in the Luzon Strait when the **USNS Hassayampa** reported 77 kt (40 m/sec) winds at a position 315 nm (585 km) to the northeast.

IV. IMPACT

Hengchun (WMO 46752) located on the southern tip of Taiwan reported sustained winds of 66 kt (33 m/sec) with gusts of 130 kt (65 m/sec) and an unusually high peak wind gust of 150 kt (75 m/sec) at 182000Z, some 30 nm (55 km) from Amy's center. The 16,000 ton freighter, **Blue River**, with 31 persons onboard, capsized and sank near the Pescadores Islands west of Taiwan. There were no survivors. On 19 July, Amy plowed into southeastern China, 99 people were killed, at least 5000 injured and over 15,000 homes destroyed.

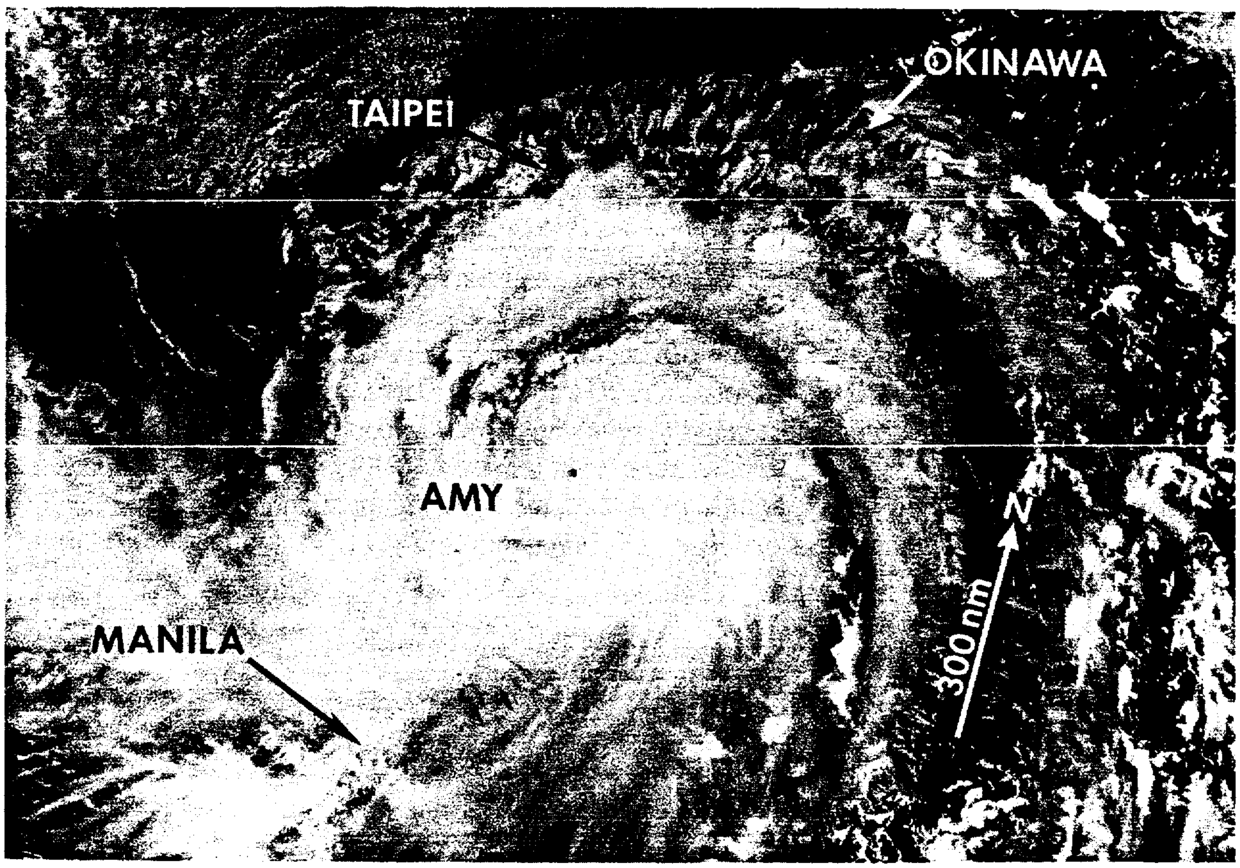


Figure 3-07-1. Amy, with an intensity near 115 kt (60 m/sec), passes through the Luzon Strait with a small 10 nm (20 km) diameter eye (180546Z July NOAA visual imagery).

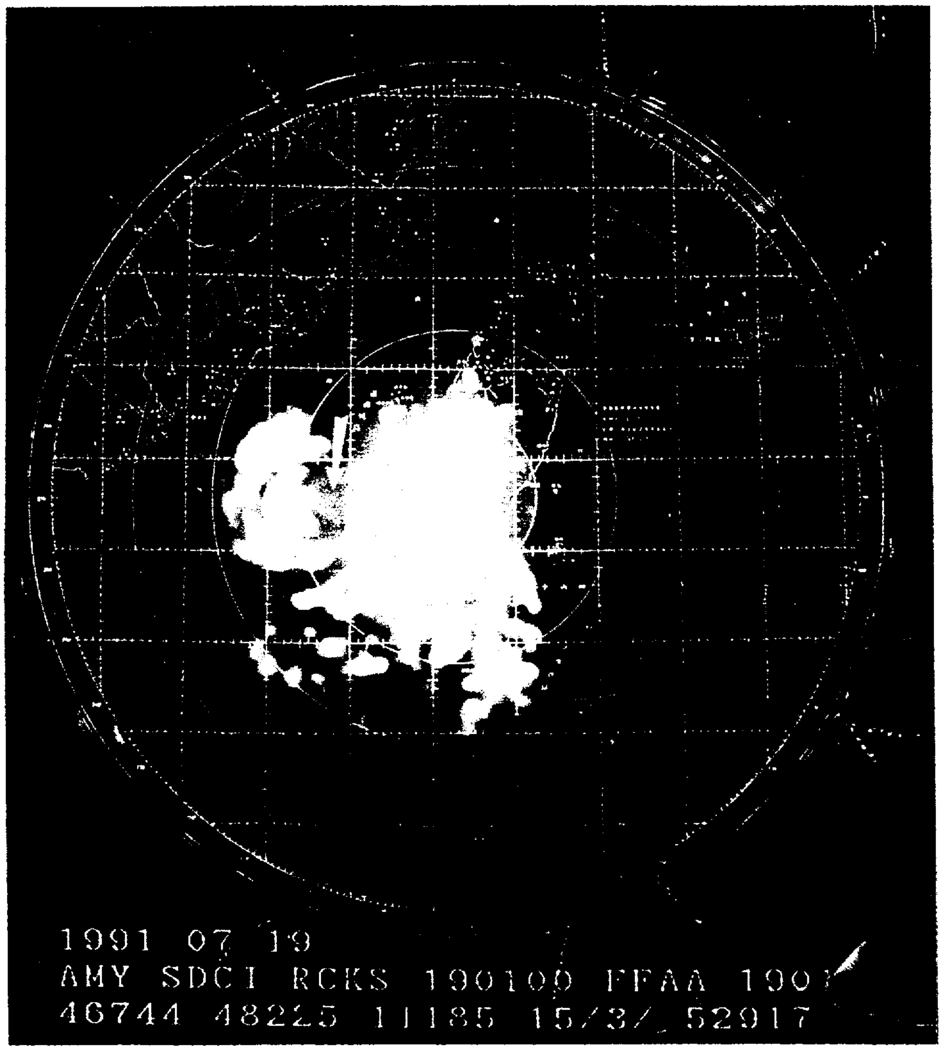
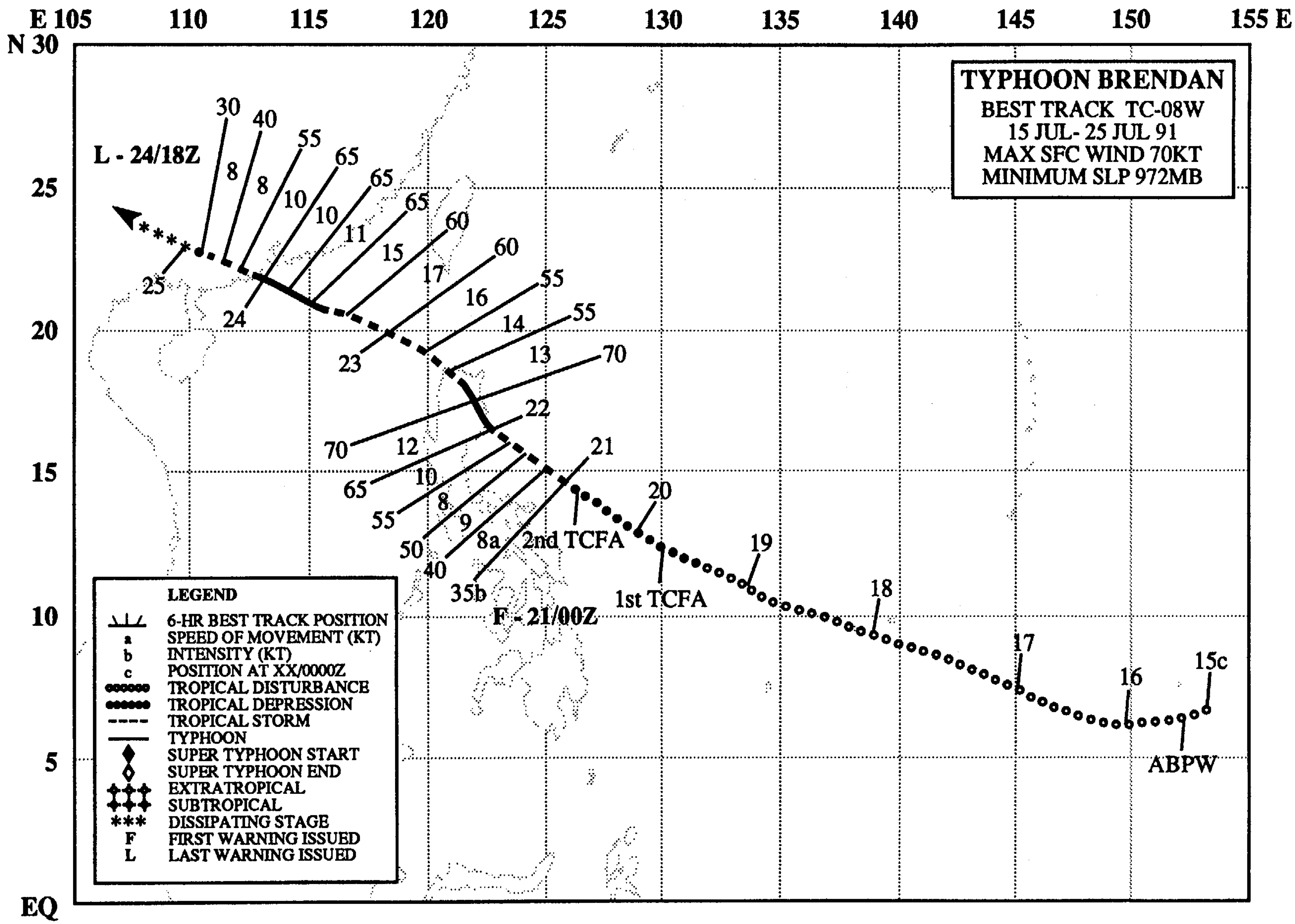


Figure 3-07-2. The radar at Kaohsiung (WMO 46744) at 190100Z July reveals tightly curved concentric rainbands surrounding Amy's eye (Photograph courtesy of the Central Weather Bureau, Taipei, Taiwan).



TYPHOON BRENDAN
BEST TRACK TC-08W
15 JUL- 25 JUL 91
MAX SFC WIND 70KT
MINIMUM SLP 972MB
E 105
110
115
120
125
130
135
140
145
150
155 E
N 30
25
20
15
10
5
EQ
L - 24/18Z
F - 21/00Z
1st TCFA
2nd TCFA
ABPW
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TYPHOON BRENDAN (08W)

I. HIGHLIGHTS

The third tropical cyclone of July, Brendan was the third straight-runner in a row. Torrential rains associated with the tropical cyclone's passage across northern Luzon unleashed lahars or avalanches of volcanic debris, mud and boulders in the valleys near Mount Pinatubo. The forecast models performed very well throughout the duration of this tropical cyclone, and JTWC's forecast errors were below average.

II. TRACK AND INTENSITY

A weak surface circulation developed 70 nm (130 km) south-southeast of Chuuk in the central Caroline Islands on 15 July. The cloud system tracked generally west-northwestward for several days until it moved into an area of increased upper level divergence in the central Philippine Sea on the nineteenth. At 191800Z, JTWC issued the first Tropical Cyclone Formation Alert. At that time the system was located approximately 230 nm (425 km) east of the Philippine island of Samar. Due to the extreme diurnal fluctuations in the system's convection which delayed intensification, JTWC re-issued the alert at 201800Z. The first visual satellite imagery available later that morning showed significant low-level cloud lines north of an organized surface circulation. This level of organization coupled with a low shear environment and warm sea surface temperatures, prompted JTWC to issue the first 72-hour tropical cyclone warning on Tropical Depression 08W at 210000Z.

Tropical Depression 08W was upgraded to Tropical Storm Brendan on the 210600Z warning, based on a Dvorak intensity estimate of 35 kt (18 m/sec). Intensification continued over the next 36 hours, and the system reached marginal typhoon intensity before making landfall over northern Luzon. Initially it appeared that the system would track more northward along the coast to the east of the Sierra Madre mountain range rather than over the mountains. However, after making landfall, Brendan continued to track northwestward across the mountains and emerged at tropical storm intensity on the northwestern coast of Luzon at 221200Z (Figure 3-08-1). As Tropical Storm Brendan accelerated to the west-northwest away from northern Luzon, it began to reintensify, attaining typhoon intensity for a second time at 230000Z (Figure 3-08-2) in the South China Sea. The peak intensity of 75 kt (39 m/sec) occurred at 231200Z, approximately 12 hours before the typhoon made landfall over southeastern China approximately 30 nm (55 km) southwest of Macau. After making landfall, Brendan continued to move northwestward and weaken. JTWC issued the final warning on this tropical cyclone at 241800Z, as it was dissipating over land.

III. FORECAST PERFORMANCE

JTWC performed well with mean forecast errors of 94, 127 and 158 nm at 24 , 48 and 72 hours respectively. In comparison, as a measure of skill the climatology-persistence model CLIPER had errors of 113, 238 and 370 nm for the same time periods. Initially, JTWC forecasts were to the south of the actual track.

IV. IMPACT

Brendan had a significant impact on both the Philippines and China. In the Philippines, torrential rainfall combined with volcanic debris from Mt. Pinatubo's June eruption to produce mudflows (lahars) up to 15 feet high in the river valleys near the volcano. Three fatalities were

reported. In addition, 1400 homes were destroyed and 10,000 people evacuated. Peripheral winds and rain from the typhoon brushed across Hong Kong causing 16 minor injuries due to flying debris. Waglan Island (WMO 45009) to the south reported winds of 55 kt (29 m/sec) gusting to 80 kt (41 m/sec) while Hong Kong's Kai Tak airport (WMO 45007), which was more sheltered, recorded winds of 35 kt (18 m/sec) gusting to 55 kt (28 m/sec). However, China was greatly impacted by Brendan, which exacerbated the flooding situation already present from abnormally high spring and early summer rainfall. At least 100 fatalities were attributed to the typhoon as it moved inland.

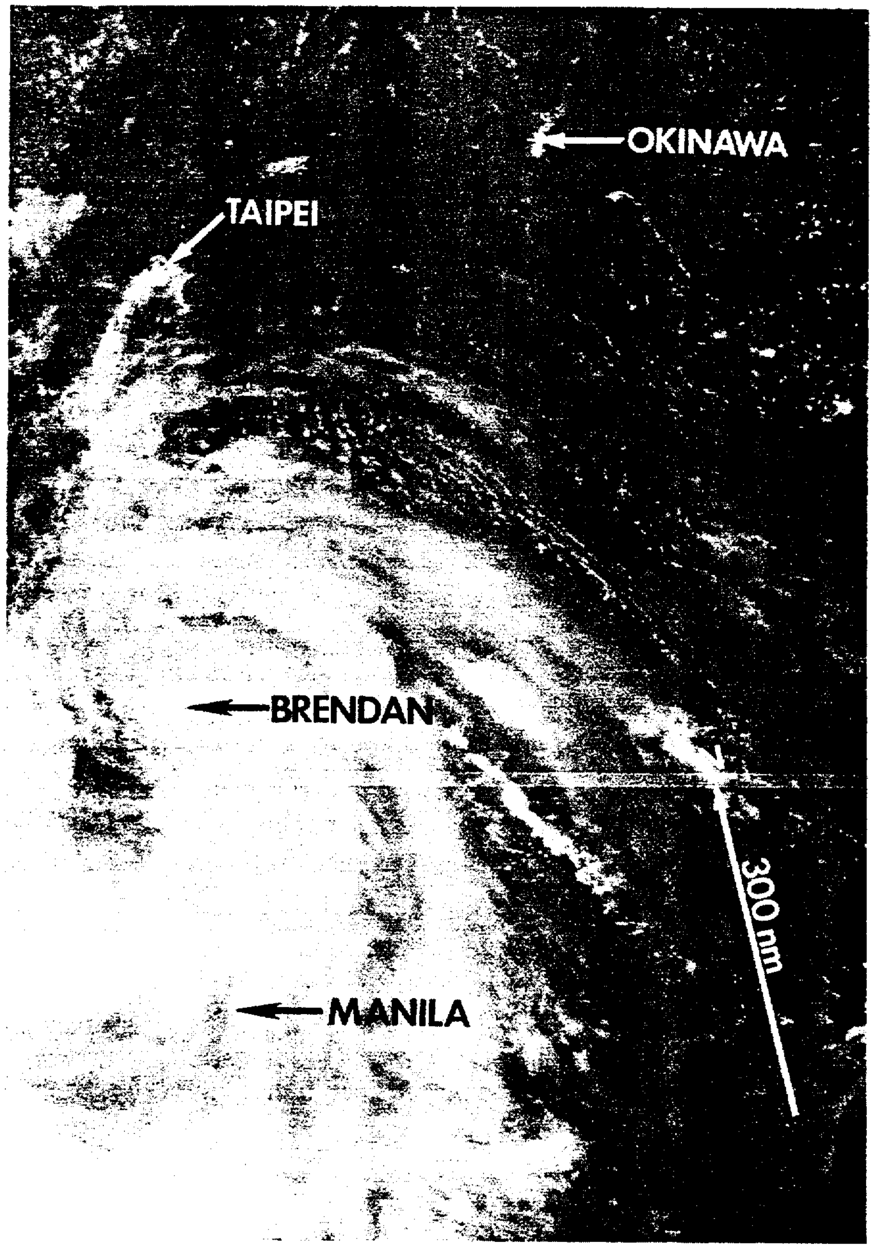


Figure 3-08-1. Brendan at tropical storm intensity shortly after moving off Luzon into the South China Sea (221253Z July DMSP infrared imagery).

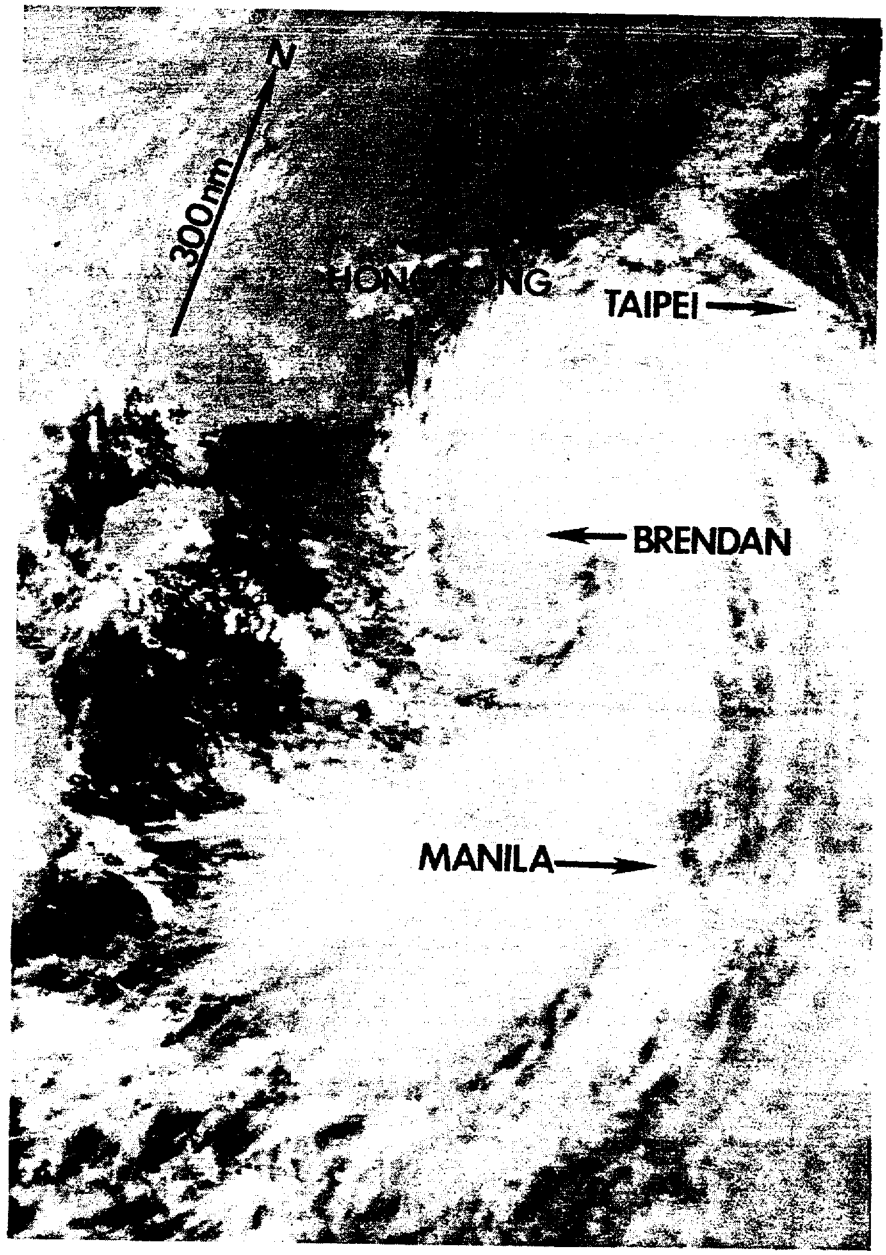
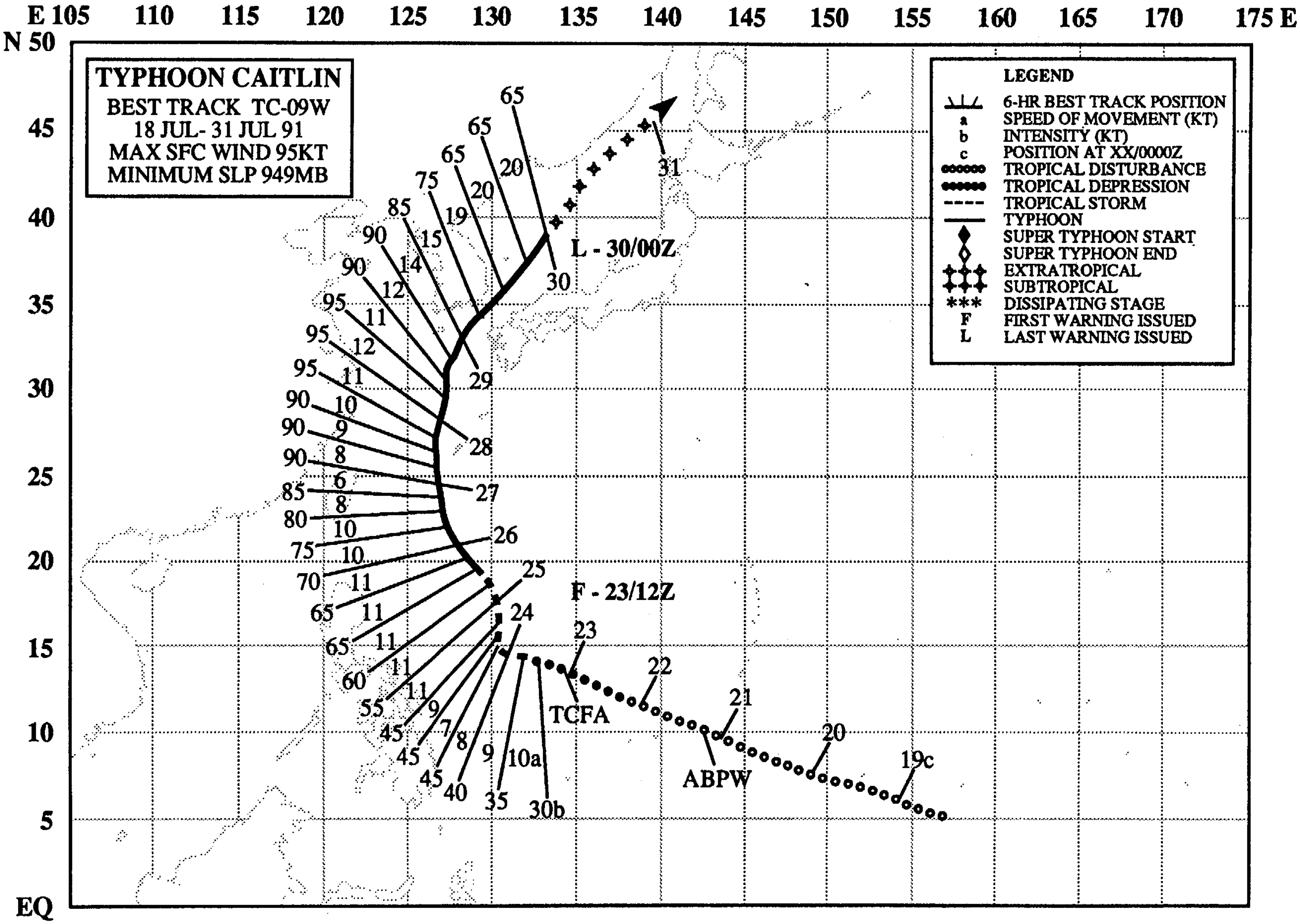


Figure 3-08-2. Brendan just after being upgraded to typhoon status in the South China Sea (230133Z July DMSP visual imagery).


TYPHOON CAITLIN
BEST TRACK TC-09W
18 JUL - 31 JUL 91
MAX SFC WIND 95KT
MINIMUM SLP 949MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L - 30/00Z
F - 23/12Z
TCFA
ABPW
19c
10a
30b
E 105
110
115
120
125
130
135
140
145
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155
160
165
170
175 E
N 50
45
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EQ

TYPHOON CAITLIN (09W)

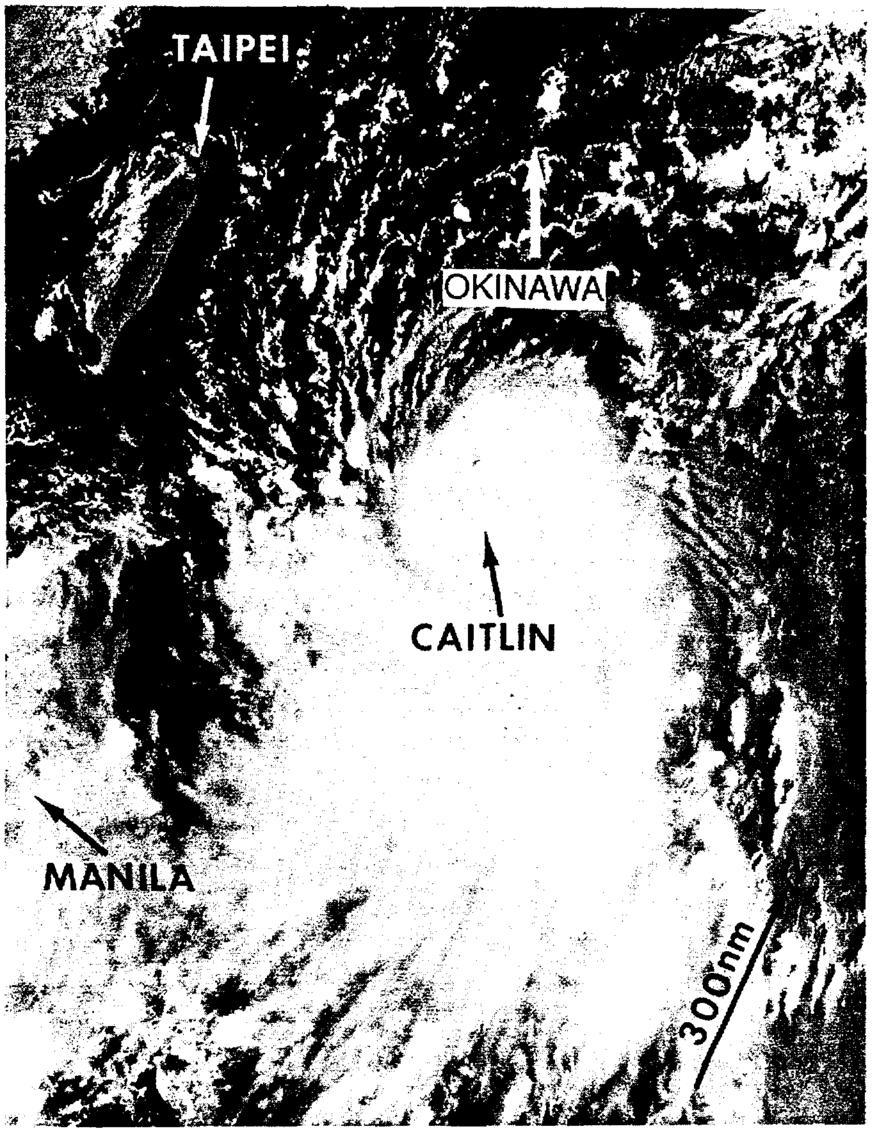


Figure 3-09-1. Caitlin has a cloud filled eye. To the north, the first line of enhanced cumulus cloud bands associated with the typhoon move across Okinawa (260028Z July DMSP visual imagery).

I. HIGHLIGHTS

After a succession of three straight-running July typhoons [Zeke (06W), Amy (07W), and Brendan(08W)], Caitlin became the first cyclone of the season to threaten Japan and Korea. Its north-oriented track was predicted by the NOGAPS model, and appeared to demonstrate the value of a newly implemented tropical cyclone bogus routine implemented at Fleet Numerical Oceanographic Center (FNOC). Much-needed rain fell on drought-stricken Okinawa as Caitlin passed west of the island.

II. TRACK AND INTENSITY

In mid-July, Caitlin developed from a disturbance in the eastern portion of the monsoon trough which extended south of Pohnpei in the eastern Caroline Islands. The disturbance moved west-northwestward, and was initially described on the 200600Z July Significant Tropical Weather Advisory as a low-level circulation with much of the deep convection displaced west of the center. On 22 July, upper-level wind shear diminished near the circulation center. Based on pressure falls of 1 to 2 mb per day at Yap (WMO 91413), and increased convective activity, a Tropical Cyclone Formation Alert was issued at 230500Z. The first warning on Tropical Depression 09W followed at 231200Z when a significant increase in convection indicated that continued intensification was likely to occur. Caitlin became a tropical storm at 240000Z.

Caitlin tracked west-northwestward until 24 July, when the subtropical ridge weakened near 130°E and allowed the tropical storm to make a sharp northward turn. For the next four days, it moved in a generally north-northwestward direction and slowly intensified. The development of an irregular, cloud-filled eye prompted an upgrade to typhoon intensity at 251200Z (Figure 3-09-1). At 271535Z, the center of the eye passed 60 nm (111 km) west of Kadena AB and Caitlin attained a peak intensity of

95 kt (49 m/sec) less than three hours later at 271800Z. After passing Okinawa, the typhoon tracked north-northeastward around the periphery of a broad mid-tropospheric subtropical ridge. On 29 July, Caitlin took a more northeastward track, accelerated through the Korea Strait, and gradually transitioned into a typhoon force extratropical low as it moved into the Sea of Japan. The final warning was issued at 300000Z when satellite imagery indicated the system had lost most of its tropical characteristics.

III. FORECAST PERFORMANCE

Initially, JTWC predicted Caitlin would follow a west-northwest track similar to the paths taken earlier by the three preceding typhoons. Of the suite of available computer forecast guidance, only the NOGAPS model indicated the cyclone would cease moving west-northwestward and assume instead a north-oriented track. This NOGAPS forecast was the subject of much speculation at the JTWC because it was uncertain if a recently implemented tropical cyclone bogus program was producing spurious output from the model. A post analysis evaluation of the bogus program, where bogus rawinsonde data derived from tropical cyclone characteristics are inserted into the NOGAPS model at the location of the tropical cyclone, showed that the program significantly improved model output in the tropics during 1991. After Caitlin made its abrupt northward turn on 24 July, JTWC forecasters responded by shifting the forecast from west-northwest to a northward track, which was consistent with the NOGAPS prognosis. As shown in Figure 3-09-2, official forecasts starting at 241800Z flip-flopped, or "windshield wiped" from northwest, to north, then north-northwest, before settling on a consistent northward track west of Okinawa. Forecast errors during this period were small,

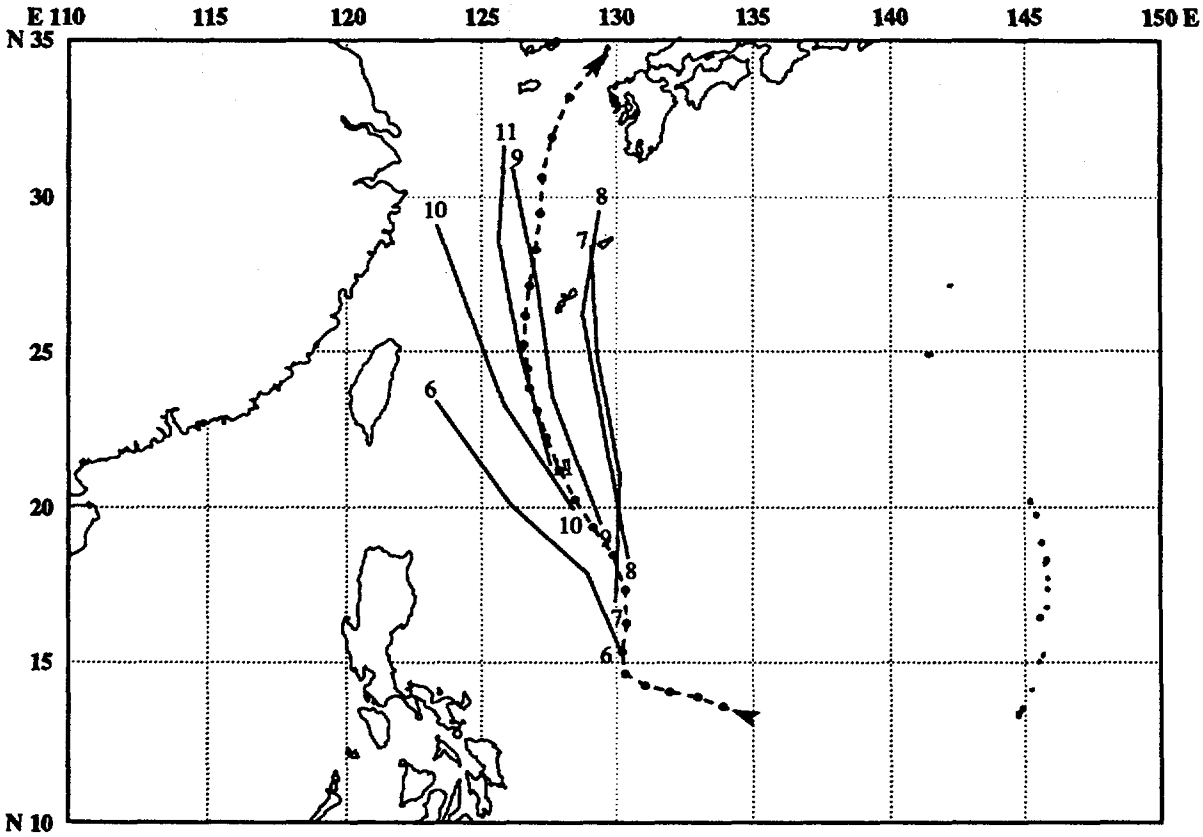


Figure 3-09-2. Comparison of JTWC forecasts issued from 241800Z to 260000Z July to the best track illustrates a significant change in JTWC track forecasts beginning at 250000Z (warning #7), and that a large degree of directional variability occurred in the subsequent track forecasts.

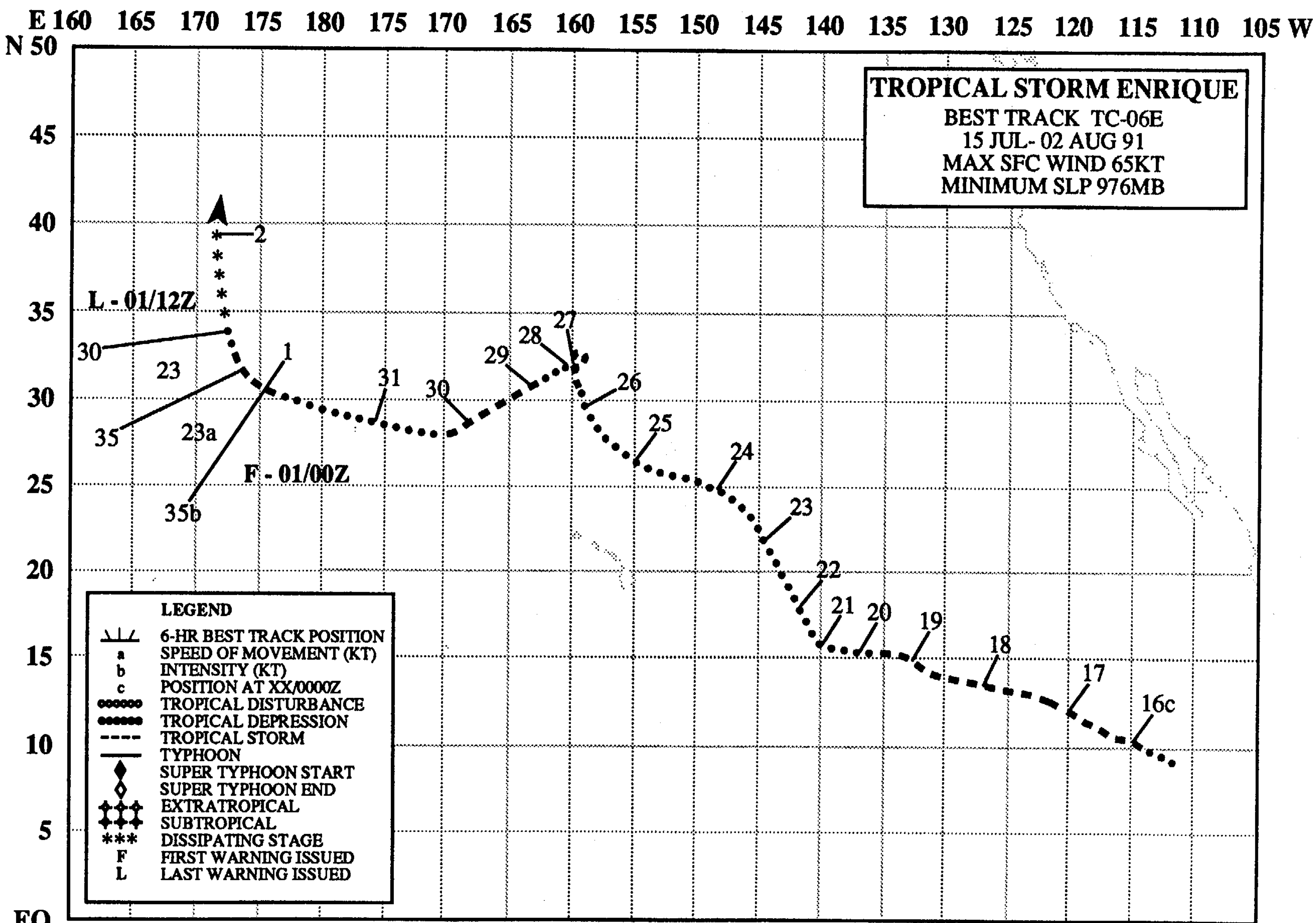
but the lack of continuity between successive warnings undermined confidence in the forecasts at a time when military units on Okinawa made the decision to evacuate. After shifting to its northward track forecast at 250000Z, JTWC forecast errors were exceptionally low, when compared with CLIPER and long term errors (Table 3-09-1). JTWC also outperformed OTCM at 24 and 48 hours.

IV. IMPACT

Caitlin provided welcome relief to the drought-stricken island of Okinawa. Kadena AB recorded a total of 12.51 inches (320 mm) of rain during a four day period, which was its heaviest precipitation since 1987. As a consequence, the reservoir level increased from only 35 percent to over 80 percent of its capacity. On Okinawa, one death was attributed to Caitlin, crop losses were estimated at $7.4 million, and U.S. military bases reported damage of more than $1.2 million. The typhoon enhanced the southwest monsoon across the northern Philippine Islands, and caused unwanted rainfall there. Manila received 8.38 inches (210 mm) of rain on 26 July, triggering avalanches of volcanic mud and debris, lahars, in the valleys near Mount Pinatubo and widespread flooding which resulted in 16 deaths and the evacuation of more than 20,000 people. Later, there were press reports of 2 deaths and over $4 million damage in Korea.

Table 3-09-1. Average 24-, 48-, and 72-hour forecast errors of the official forecast (JTWC) compared to CLIPER and OTCM for the time period 250000Z to 300000Z July, and the long term average JTWC errors.

	JTWC	CLIP	OTCM	Average
24 HR (17 cases)	70	81	91	120
48 HR (13 cases)	94	138	112	240
72 HR (09 cases)	146	266	126	360


TROPICAL STORM ENRIQUE
BEST TRACK TC-06E
15 JUL- 02 AUG 91
MAX SFC WIND 65KT
MINIMUM SLP 976MB
E 160
165
170
175
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105 W
N 50
45
40
35
30
25
20
15
10
5
EQ
L - 01/12Z
F - 01/00Z
2
1
30
23
35
23a
35b
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16c
LEGEND
6-HR BEST TRACK POSITION
SPEED OF MOVEMENT (KT)
INTENSITY (KT)
POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED

TROPICAL STORM ENRIQUE (06E)

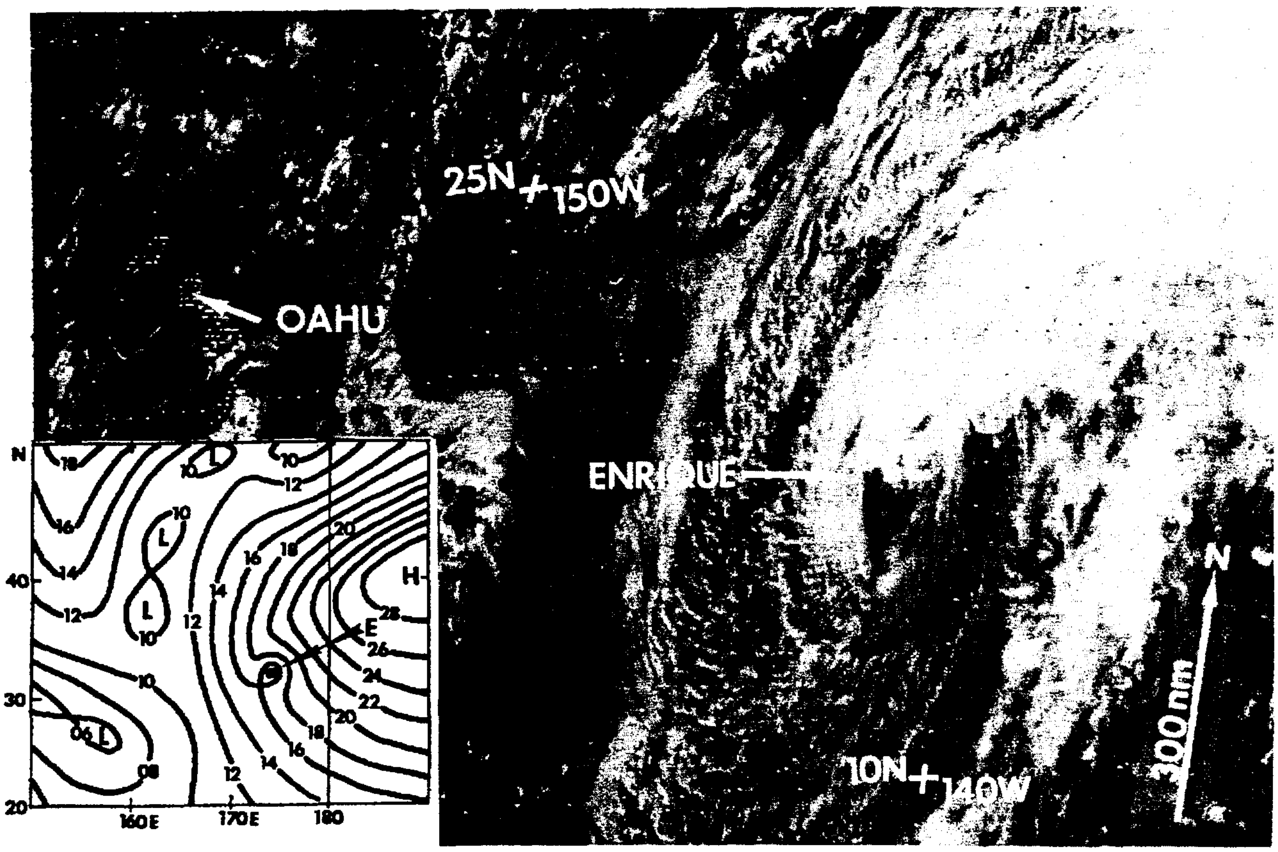
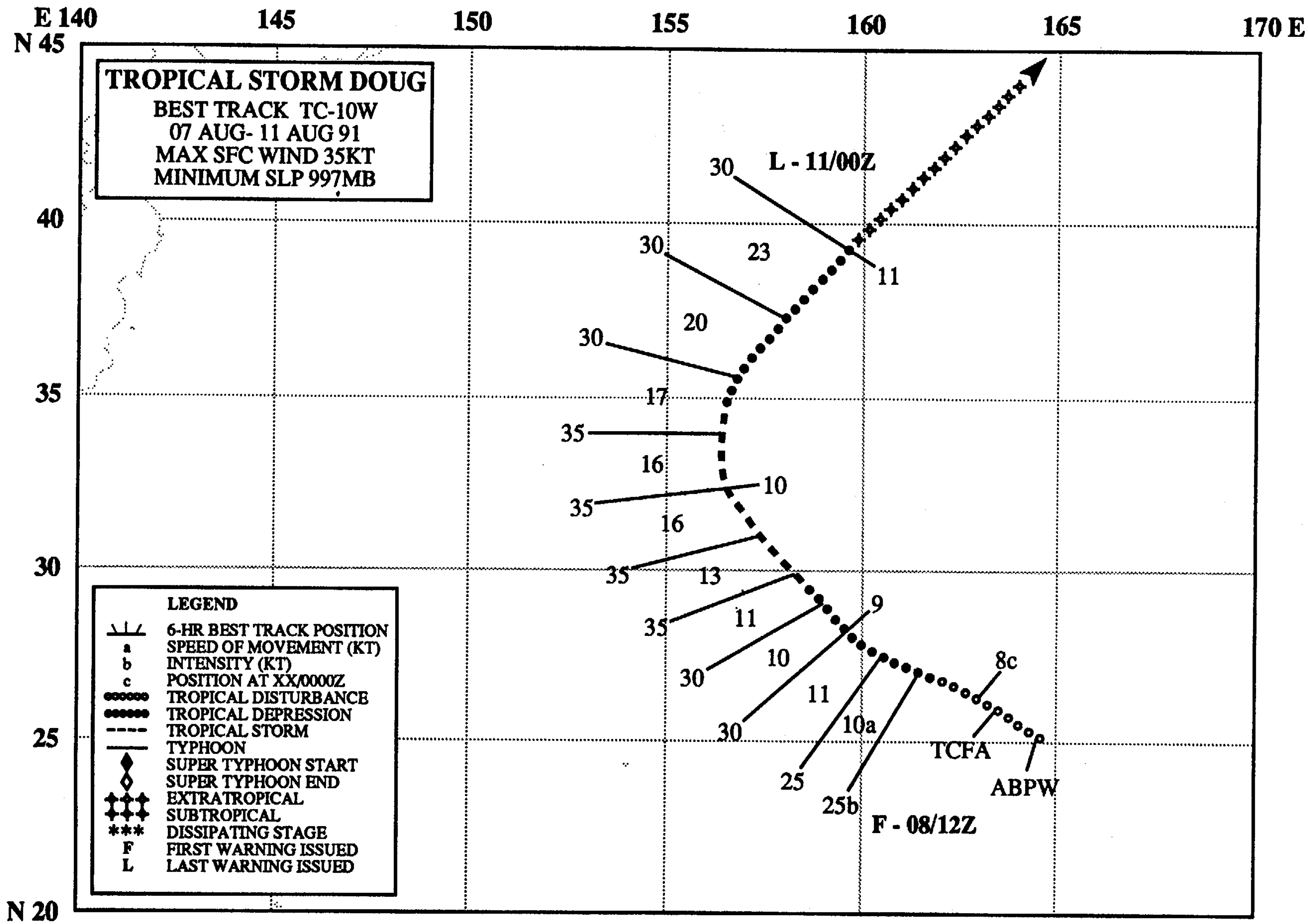


Figure 3-06E-1 Tropical Storm Enrique as a dissipating circulation east of the Hawaiian Islands (220000Z July GOES visual imagery).

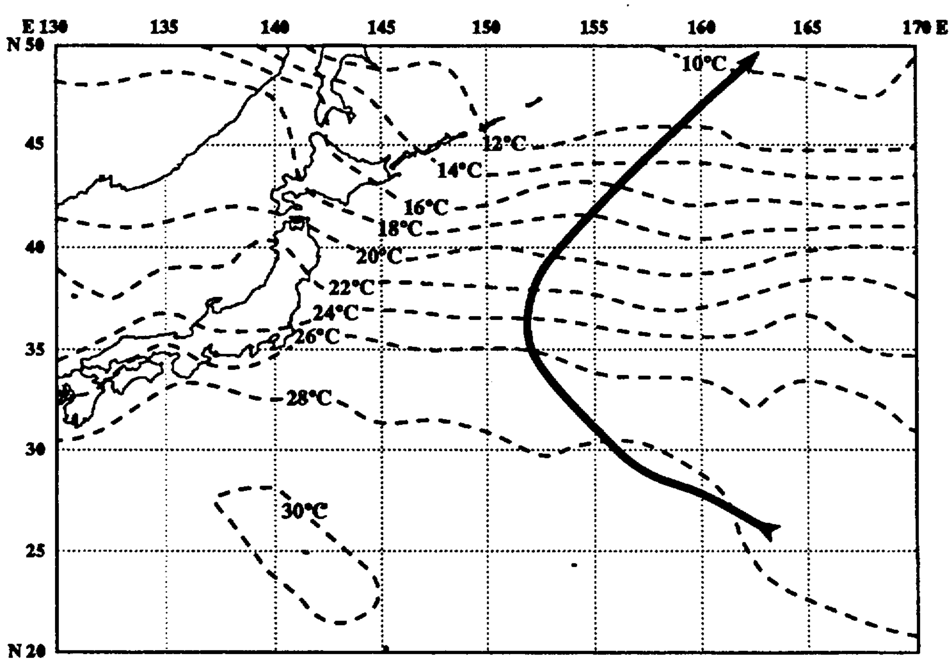
Enrique was a rare tropical cyclone that was warned on by three separate U.S. tropical cyclone warning centers. Enrique began in the Eastern Pacific, the National Hurricane Center's area of responsibility, trekked 4900 nm (9100 km) across the North Pacific Ocean through the Central Pacific Hurricane Center's area, then after weakening, regenerated and dissipated in JTWC's area of responsibility. Over the past 20 years, Typhoon Georgette (1986) was the only other Eastern Pacific tropical cyclone to cross the international date line. After the first warning was issued by the National Hurricane Center at 151800Z, Enrique tracked west-northwestward and intensified to minimal hurricane intensity at 170600Z before weakening as it approached 140°W. Enrique maintained a weak circulation during the next five days as it passed north of the Hawaiian Islands. Then, on 27 July, it executed a clockwise loop and headed southwestward while re-intensifying to 45 kt (23 m/sec). Increased vertical wind shear caused the circulation to weaken once again as it headed toward Midway Island. Visual satellite imagery of the small system at 291938Z revealed that it had a spiral low-cloud pattern indicative of a closed surface circulation. This prompted the JTWC to mention the small circulation on the 300600Z Significant Tropical Weather Advisory. Increased convection and a pressure fall of 7 mb observed at Midway Island (WMO 91066) as the system passed to the north led JTWC to issue a warning at 010000Z August. Enrique's tiny pressure signature was deeply embedded in the large maritime high to the northeast (as shown in the insert). As the tropical storm tracked to the north-northwest, it encountered strong upper-level wind shear and, once again, lost all of its deep convection. The last warning was issued at 011200Z.

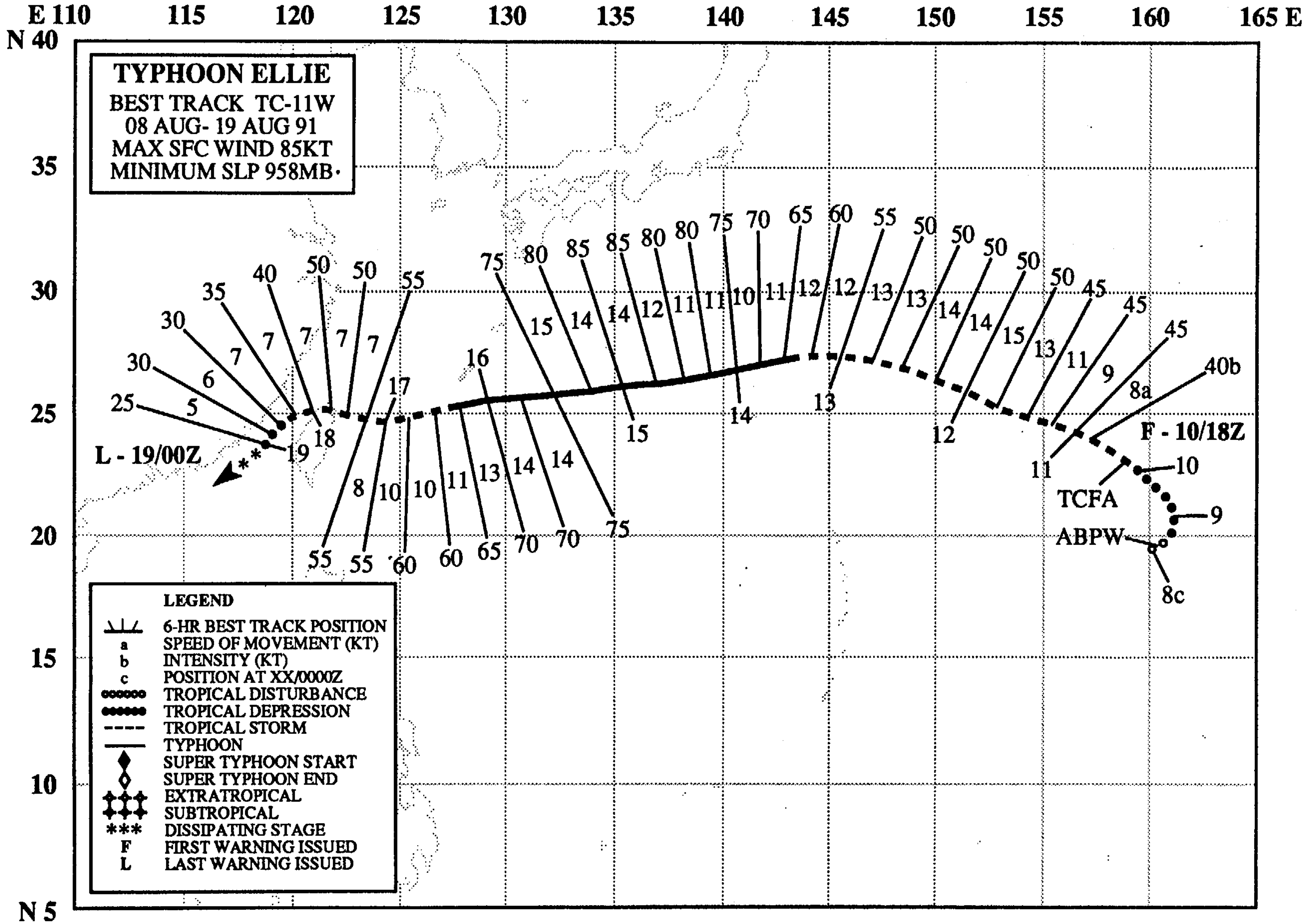

TROPICAL STORM DOUG
BEST TRACK TC-10W
07 AUG- 11 AUG 91
MAX SFC WIND 35KT
MINIMUM SLP 997MB
E 140
145
150
155
160
165
170 E
N 45
40
35
30
25
N 20
L - 11/00Z
F - 08/12Z
TCFA
ABPW
30
23
11
20
17
35
16
10
13
9
8c
10a
25
25b
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TROPICAL STORM DOUG (10W)

Figure 3-10-1 Tropical Storm Doug heads northwestward into colder waters (see lower left) as Typhoon Ellie (11W) begins to intensify (090311Z August NOAA visual imagery).

Doug was the first of a series of six tropical cyclones to form in August as part of a large NSS monsoon gyre (Lander, 1992). The tropical disturbance that became Doug was initially discussed in the 070600Z Significant Tropical Weather Advisory. A Tropical Cyclone Formation Alert was issued at 071955Z when convection developed around a well-defined low-level circulation center. Increased deep central convection prompted the first Tropical Depression warning at 081200Z. Doug was upgraded to a tropical storm 24-hours later as it tracked northwestward to the subtropical ridge axis, and then recurved ahead of a mid-tropospheric trough. Doug failed to intensify beyond minimal tropical storm intensity because it moved rapidly northward into an area of colder sea surface temperatures and increased vertical shear before transitioning into an extratropical cyclone.




TYPHOON ELLIE
BEST TRACK TC-11W
08 AUG- 19 AUG 91
MAX SFC WIND 85KT
MINIMUM SLP 958MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L - 19/00Z
F - 10/18Z
TCFA
ABPW
E 110
115
120
125
130
135
140
145
150
155
160
165 E
N 40
35
30
25
20
15
10
N 5

TYPHOON ELLIE (11W)

I. HIGHLIGHTS

The second tropical cyclone of August, Typhoon Ellie, formed as part of a larger NSS monsoon gyre (Lander, 1992) a day after Doug (10W) formed. Ellie, also the second midget typhoon of 1991, maintained a generally westward track 2400 nm (4440 km) across the western North Pacific from just west of Wake Island to Taiwan.

II. TRACK AND INTENSITY

After its initial counter-clockwise orbit of the center of the larger NSS monsoon gyre on 8 and 9 August, Ellie tracked westward, embedded in the mid-level flow south of the axis of a narrow subtropical ridge. Instead of recurving immediately behind Doug (10W), Ellie took a more westerly track as increased subsidence behind the passing mid-tropospheric trough associated with Doug (10W) caused ridging between the two tropical cyclones. Later, after crossing northern Taiwan and losing its central convection, the midget's residual vortex was carried southwestward with the low-level flow.

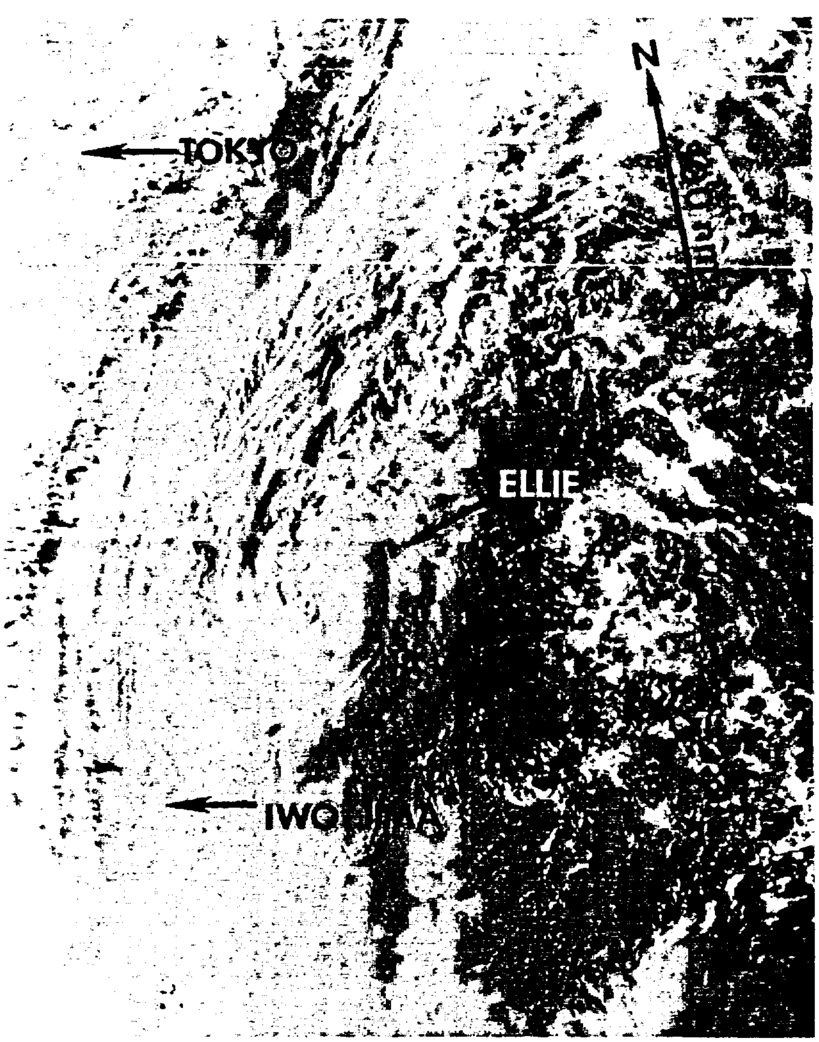


Figure 3-11-1. Ellie is upgraded to a typhoon as it develops a visible eye (130838Z August DMSP visual imagery).

Ellie developed as a weak disturbance between Wake Island and Minami-Tori Shima, and was first mentioned on the 080600Z Significant Tropical Weather Advisory. Visual satellite imagery at 100300Z showed that Ellie's central dense overcast (CDO) was very compact, and was associated with a low-level circulation. Synoptic data at the same time included a 25 kt (13 m/sec) wind report and a 1002 mb surface pressure nearby. Based on these data, JTWC issued a Tropical Cyclone Formation Alert at 100500Z. The first warning followed at 101800Z, and the system was upgraded to tropical storm intensity at 110000Z. The post analysis showed that this midget system actually had a central dense overcast and estimated winds of 35 kt (18 m/sec) at 100600Z. Ellie reached typhoon intensity at 131200Z (Figure 3-11-1) and later peaked at 85 kt (44 m/sec) at 141800Z (Figure 3-11-2). As Ellie began to weaken, the

concentration and organization of the tropical cyclone's small CDO began to fluctuate. Increasing vertical shear and interaction with the mountainous island of Taiwan led to Ellie's demise and subsequent dissipation over water in the Taiwan Strait on 19 August.

III. FORECAST PERFORMANCE

The forecast aids, CLIM, CLIPER, AND HPAC, consistently called for recurvature (Figure 3-11-3). Initially, the dynamic and statistical-dynamical aids also favored a northwestward track through the subtropical ridge. As a result JTWC's forecasts initially reflected a recurvature scenario. Nevertheless Ellie moved south of the forecast break in the ridge and tracked to the west. Once the typhoon passed this weak bifurcation point, the dynamic models adopted an under-the-ridge scenario. Still, they sensed a weak ridge and, unable to account for the small size of the typhoon, continued to indicate that Ellie's track would gain latitude. In keeping with this dynamic guidance, JTWC's forecasts also provided predictions to the right of the verifying final best track. After the tropical cyclone moved southwest of Okinawa, and approximately 72 hours prior to dissipation, the dynamic aids began to sense the ridging over Asia and their track guidance moved closer to the actual track (Figure 3-11-4).

IV. IMPACT

Although Ellie persisted for over a week, threatened Okinawa, the southern Ryukyu Islands, northern Taiwan and maritime interests along the way, no reports of significant damage or fatalities were received.

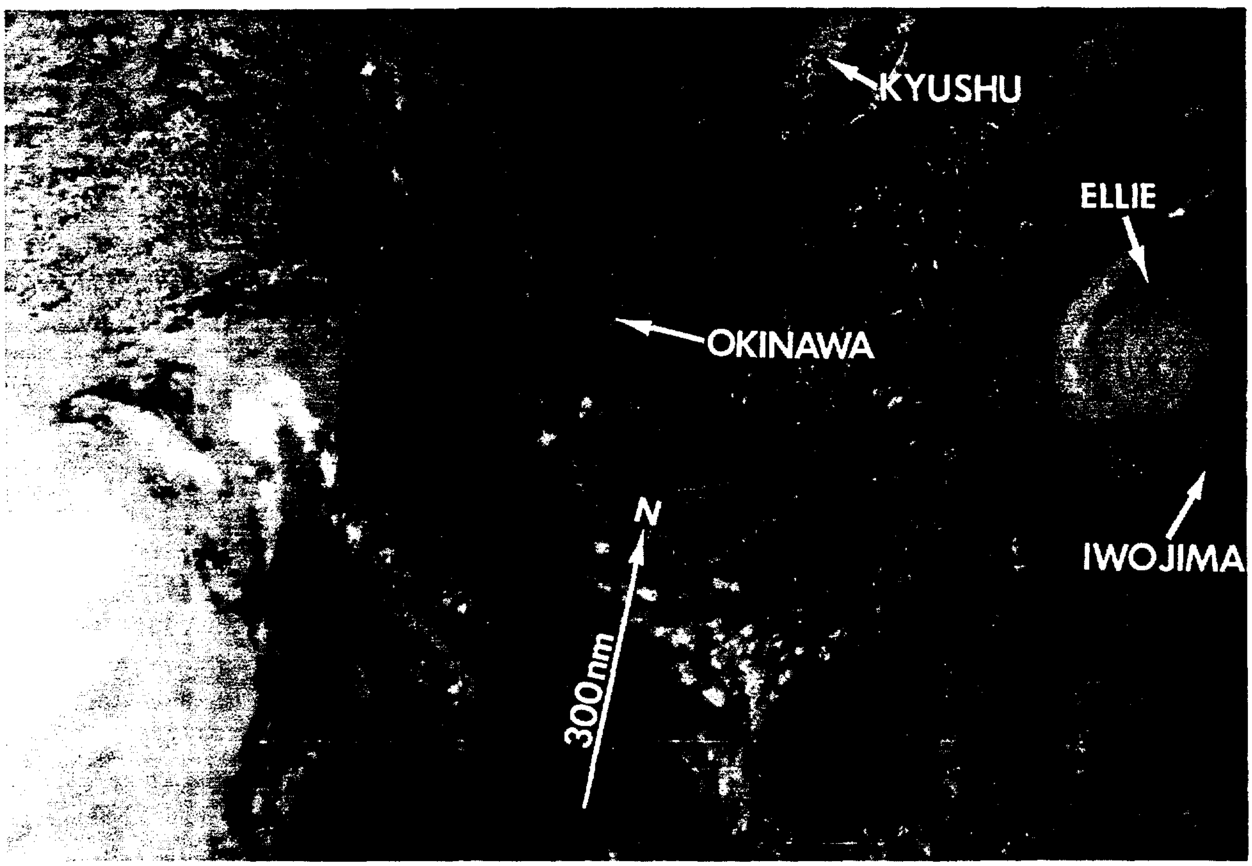
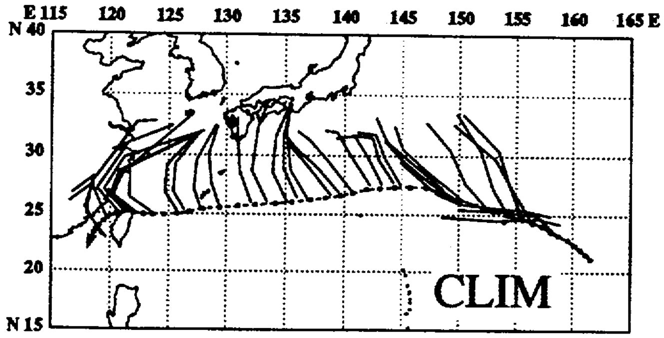
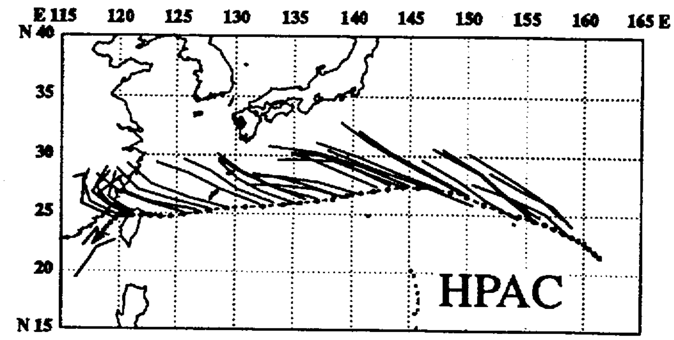


Figure 3-11-2. A partially cloud filled eye is visible as Ellie nears its maximum intensity in the northern Philippine Sea (140537Z August NOAA visual imagery).





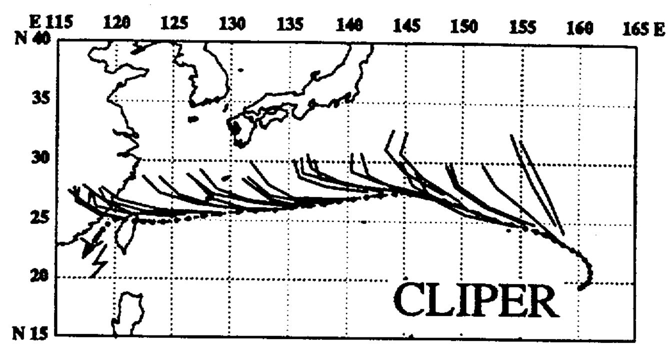
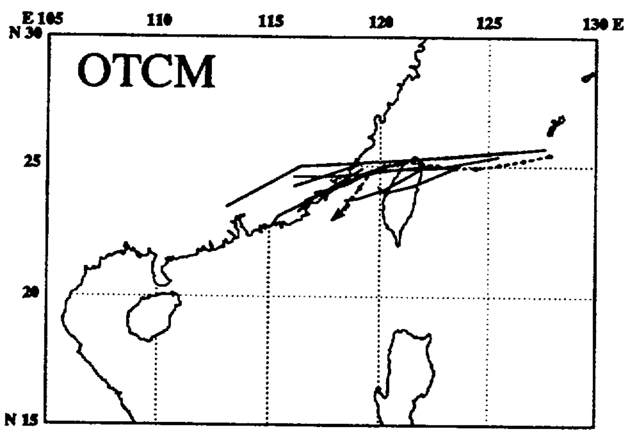
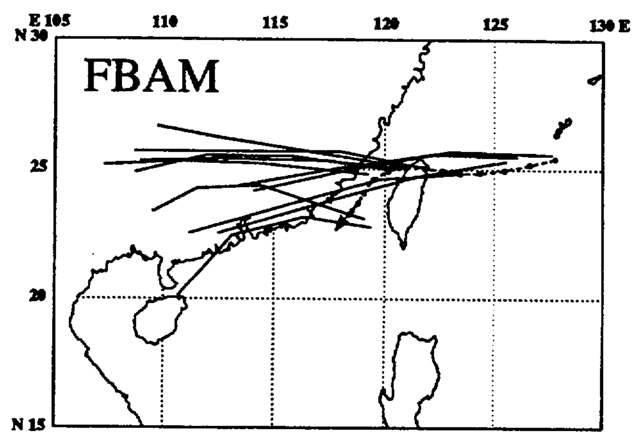


Figure 3-11-3. Climatological and statistical track guidance for Ellie (clockwise from top left): CLIMatology (CLIM), Half Persistence And Climatology (HPAC), CLImatology and PERsistence (CLIPER). These aids were consistently to the right of the verifying best track.





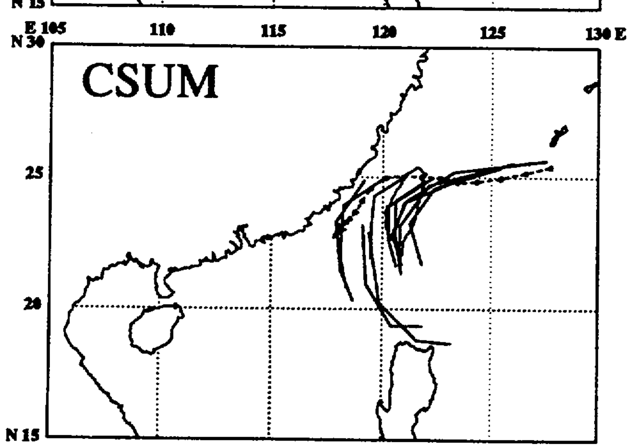
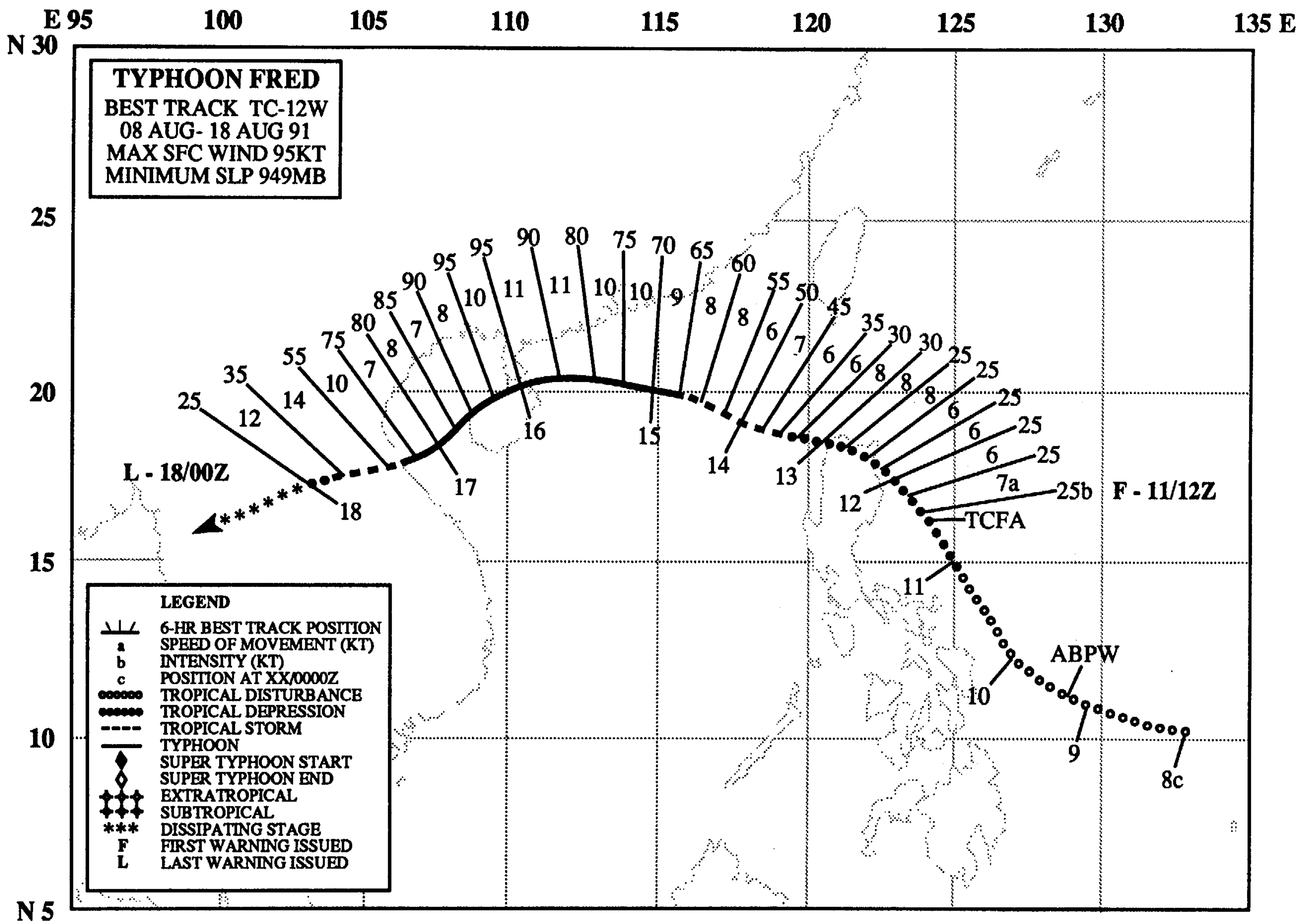


Figure 3-11-4. Objective guidance from the One-way Tropical Cyclone Model (OTCM) , FNOC Beta and Advection Model (FBAM) , and the Colorado State University Model (CSUM) correctly indicates westward to southwestward tracks after 160600Z as Ellie passed to the southwest of Okinawa.


TYPHOON FRED
BEST TRACK TC-12W
08 AUG- 18 AUG 91
MAX SFC WIND 95KT
MINIMUM SLP 949MB
E 95
100
105
110
115
120
125
130
135 E
N 30
25
20
15
10
N 5
L - 18/00Z
F - 11/12Z
TCFA
ABPW
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TYPHOON FRED (12W)

I. HIGHLIGHTS

Typhoon Fred was a part of two, three-storm outbreaks that occurred in mid-August. The first involved Typhoon Ellie (11W) and Tropical Depression 13W, and the second involved Ellie (11W) and Typhoon Gladys (14W). Fred skirted the northern coasts of Luzon and Hainan Island before dissipating over Southeast Asia. From the onset, JTWC correctly predicted that Fred would track generally to the west, and as a result, forecast track errors were very low, in fact, the lowest for any tropical cyclone of the year.

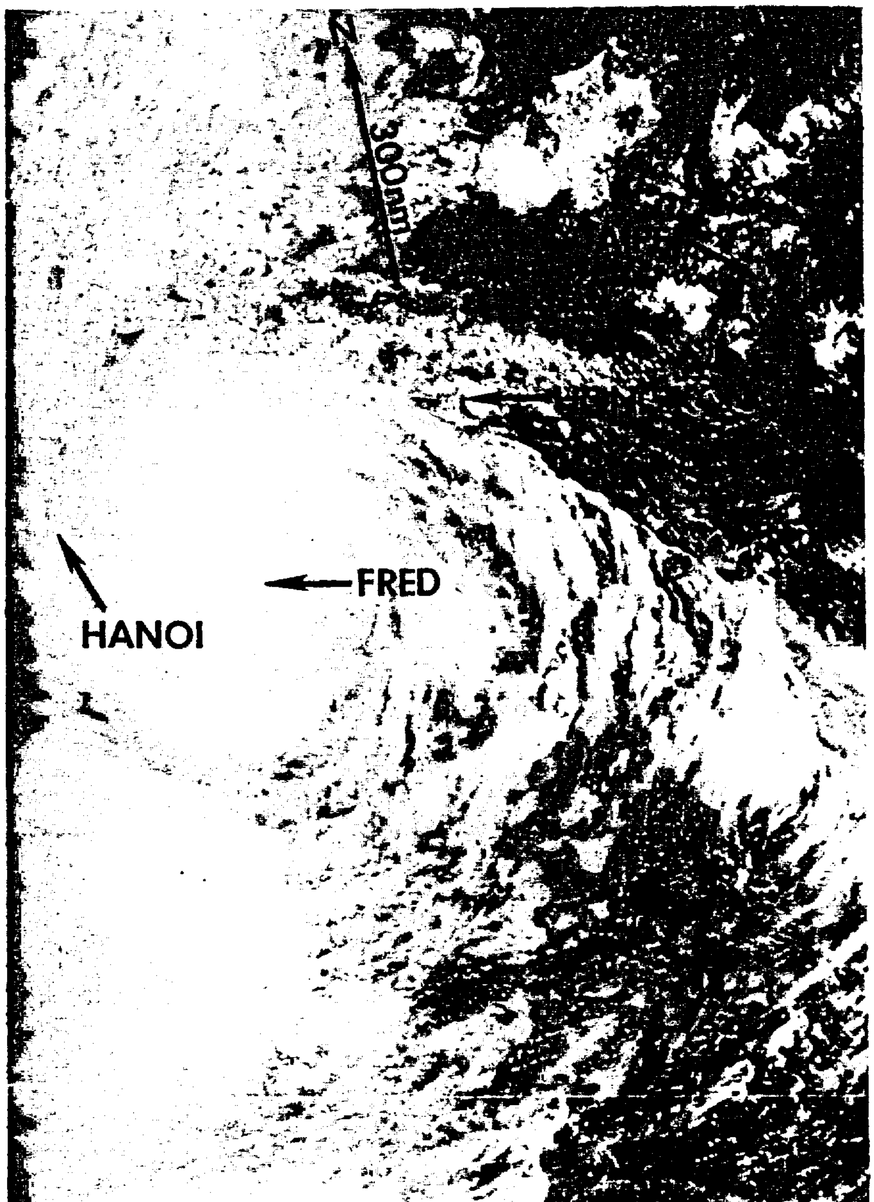


Figure 3-12-1. Typhoon Fred at minimal typhoon intensity, 120 nm (220 km) south of Hong Kong (150030Z August DMSP visual imagery).

II. TRACK AND INTENSITY

Fred originated as a broad, poorly organized circulation in the monsoon trough east of the central Philippine Islands on 8 August, and was first mentioned on the Significant Tropical Weather Advisory at 090600Z. A Tropical Cyclone Formation Alert was issued at 110900Z when animated satellite imagery revealed cyclonic motion of deep convective elements around a common center. The first warning on Tropical Depression 12W closely followed the alert, and was issued at 111200Z, when the "spin up" observed earlier from the satellite was supported by synoptic reports. After crossing northern Luzon, Fred headed west-northwestward, steered by a subtropical ridge which extended from the northern Philippine Sea southwestward into southern China. Intensifying as it moved west-northwestward, the tropical cyclone became a tropical storm at 131200Z and reached typhoon intensity at 141800Z (Figure 3-12-1), with the presentation of a visible eye in satellite imagery. On 15 August, the narrow ridge over southern China persisted and Typhoon Fred

passed to the south of Hong Kong, heading for Hainan Dao. After passing along the northwest coast of Hainan Dao on 16 August with estimated maximum sustained winds of 95 kt (49 m/sec), the typhoon weakened and took an unanticipated southwestward track across the Gulf of Tonkin. Fred continued to track west-southwestward, and the final warning was issued at 180000Z as the low was dissipating over the mountainous terrain of Southeast Asia.

II. FORECAST PERFORMANCE

JTWC forecast performance on Typhoon Fred was noteworthy. Overall, mean forecast track errors were 65, 109, and 131 nm (120, 200 and 240 km) at 24, 48 and 72 hours, respectively. In comparison, the Persistence-Climatology model, CLIPER, had errors of 93, 195 and 339 nm (170, 360 and 630 km) for the same period. The early intensity forecasts correctly indicated that Fred would attain typhoon intensity in the South China Sea.

IV. IMPACT

Heavy rains fell on Luzon as Fred crossed the northern part of the island and triggered lahars or mudslides of volcanic ash and debris in the river valleys near Mount Pinatubo. Over 100 homes were destroyed and thousands of people were forced to evacuate areas near the volcano. A 20,000 ton oil exploration barge capsized and sánk 65 nm (120 km) east of Hong Kong on 15 August. Of the 195 crew members on board the 420 foot long **Derrick Barge 29,** 22 perished, including 4 divers who were trapped in a saturation diving chamber beneath the barge. At-sea rescues of the 173 survivors were accomplished by helicopter and tugboat. In the Chinese island province of Hainan, at least 16 died during Fred's passage.

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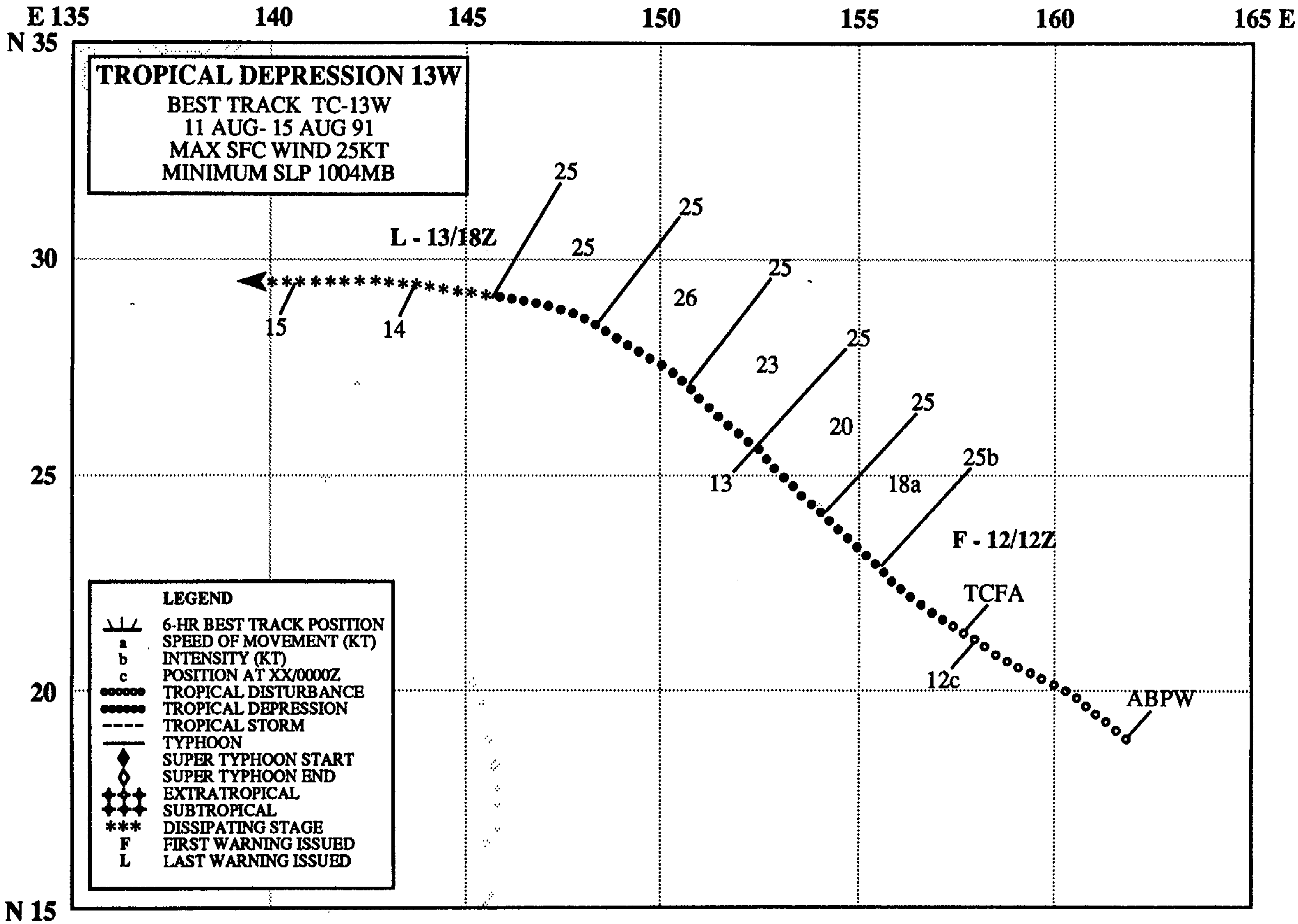

TROPICAL DEPRESSION 13W
BEST TRACK TC-13W
11 AUG- 15 AUG 91
MAX SFC WIND 25KT
MINIMUM SLP 1004MB
E 135
140
145
150
155
160
165 E
N 35
30
25
20
N 15
L - 13/18Z
F - 12/12Z
TCFA
ABPW
15
14
13
12c
25
25
25
25
25
25
25b
26
23
20
18a
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TROPICAL DEPRESSION 13W

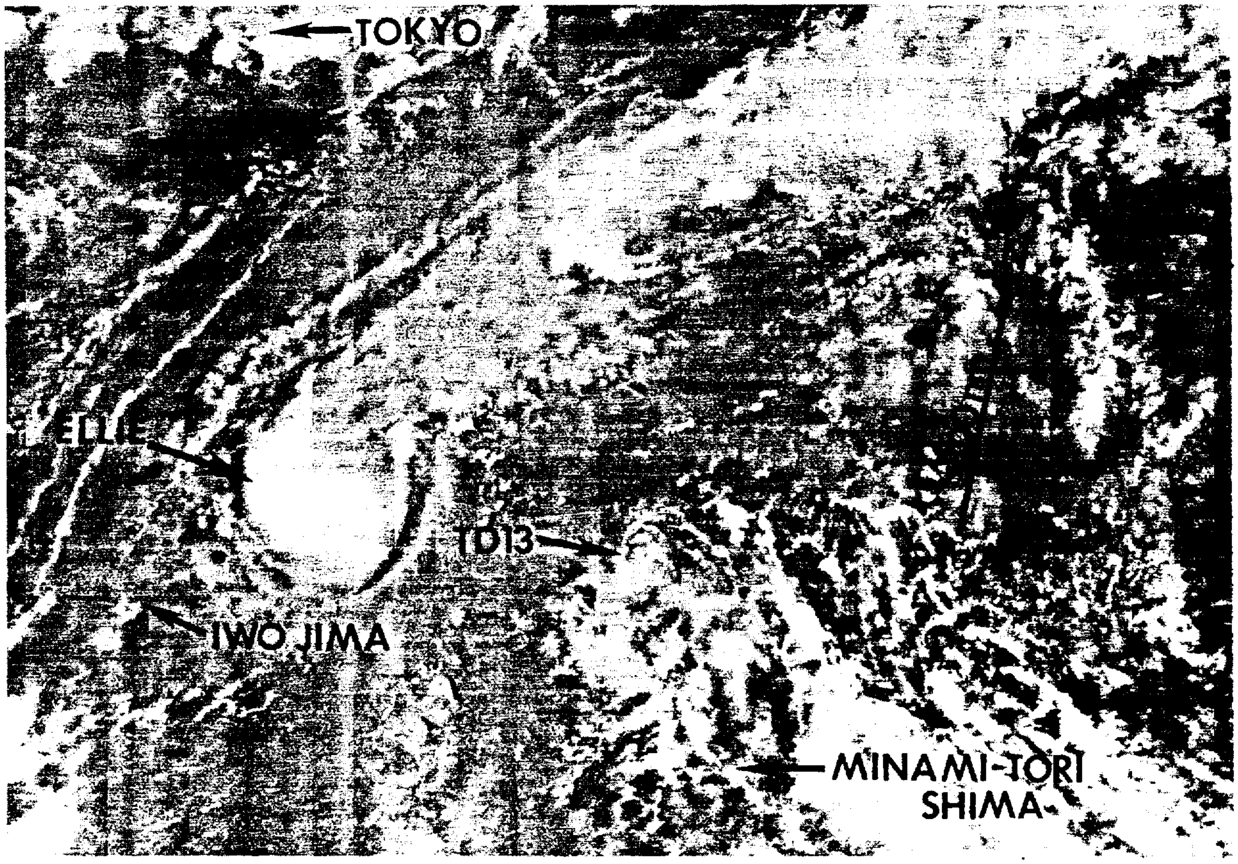
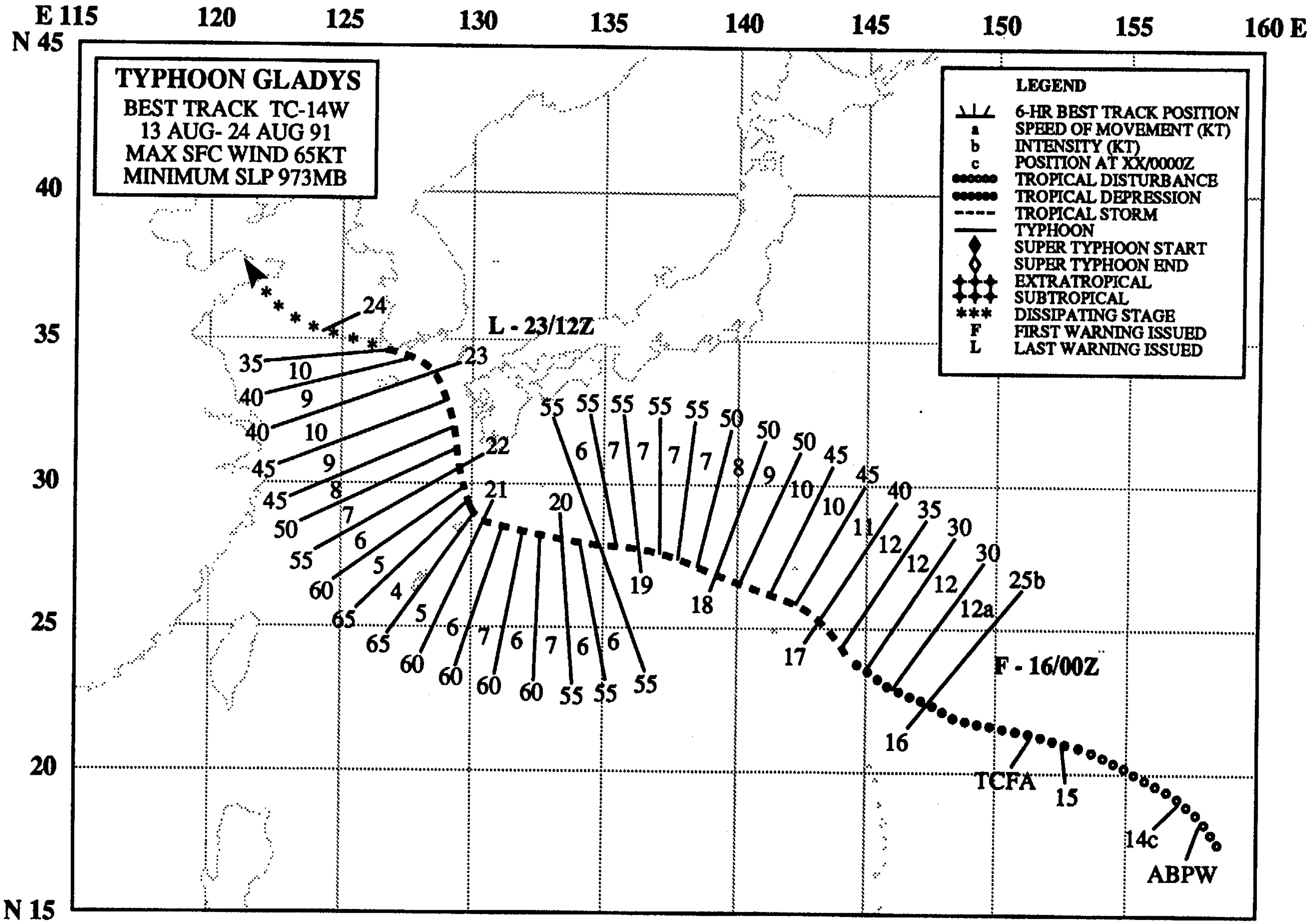


Figure 3-13-1 Tropical Depression 13W dissipates east of Typhoon Ellie (11W)(130406Z August NOAA visual imagery).

Tropical Depression 13W formed as a low pressure area in the same NSS monsoon gyre (Lander, 1992) as Typhoon Ellie (11W), and then tracked northwestward in Ellie's wake. Tropical Depression 13W was marked by large diurnal fluctuations in convection which slowed the development of strong surface winds. The disturbance was first mentioned on the Significant Tropical Weather Advisory at 110600Z. Following its next diurnal flare-up in convection, JTWC issued a Tropical Cyclone Formation Alert at 120130Z. Based on synoptic reports of 25 kt (13 m/sec) winds within 100 nm (185 km) of the circulation center and a Dvorak current intensity estimate of 25 kt (13 m/sec), the first warning was issued at 121200Z. Shortly afterward, convection decreased and visual satellite imagery of the remaining low-level circulation revealed that the cyclone center was poorly organized. When convection failed to redevelop around the center, JTWC issued its final warning on Depression 13W at 131800Z.


TYPHOON GLADYS
BEST TRACK TC-14W
13 AUG- 24 AUG 91
MAX SFC WIND 65KT
MINIMUM SLP 973MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 115
120
125
130
135
140
145
150
155
160 E
N 45
40
35
30
25
20
N 15
L - 23/12Z
F - 16/00Z
TCFA
ABPW
14c
15
16
17
18
19
20
21
22
23
24
25b
12a

TYPHOON GLADYS (14W)

I. HIGHLIGHTS

Typhoon Gladys was the largest and the fourth of six tropical cyclones generated by a NSS monsoon gyre active during the month of August. While Gladys' wind field continued to expand as it tracked southwest of Japan, there was only a small change in minimum sea-level pressure, providing a good example of a cyclone that "strengthened" significantly but did not "intensify" significantly. Despite consistently outstanding track forecasts, JTWC over-forecast the cyclone's potential for intensification.

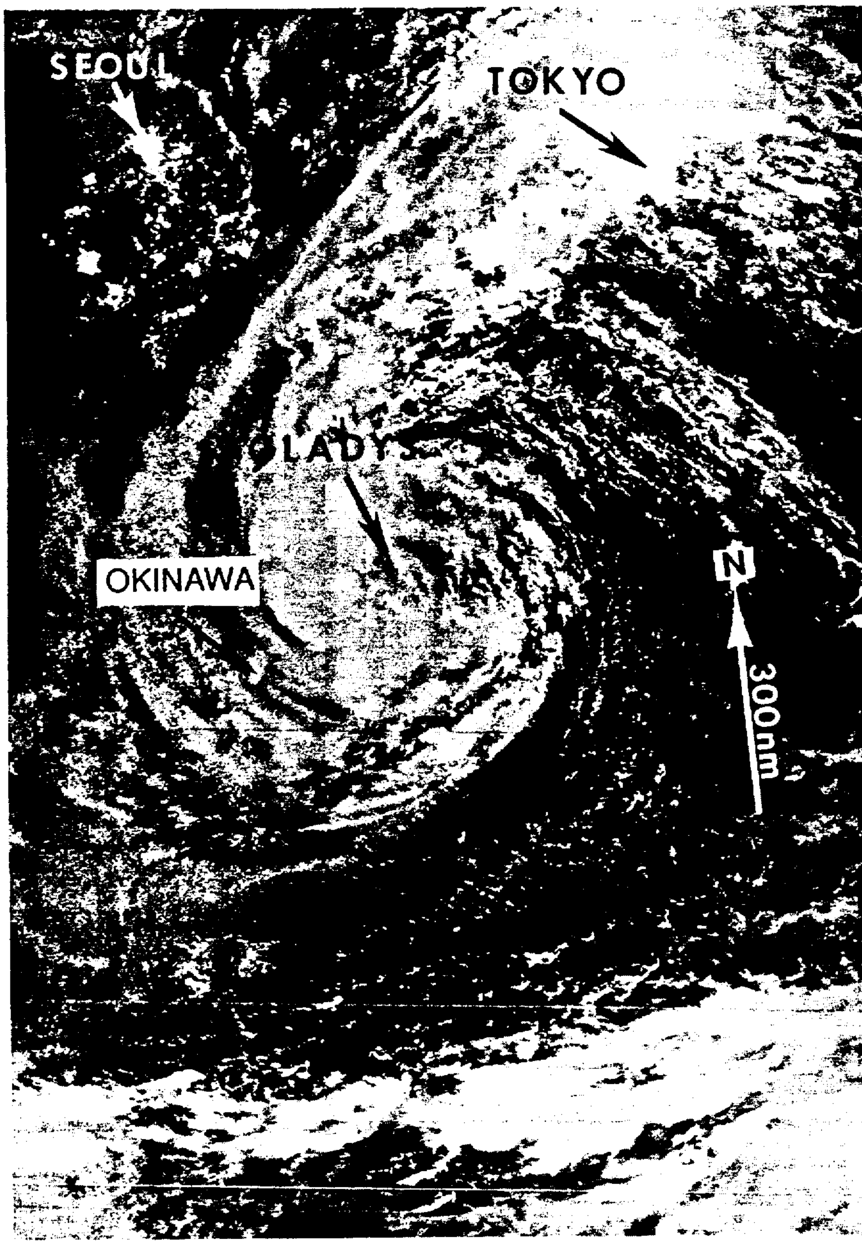


Figure 3-14-1. Tropical Storm Gladys approaches the northern Ryukyu Islands. At this time, land stations 360 nm (665 km) northeast of the center reported winds in excess of 35 kt (18 m/sec) (201235Z August DMSP moonlight visual imagery).

II. TRACK AND INTENSITY

Developing from an active NSS monsoon gyre in mid-August, Gladys tracked west-northwestward for most of its lifetime, south of an east-west oriented subtropical ridge. Initially described on the 131800Z Significant Tropical Weather Advisory as a weak cyclonic circulation, it slowly gained convective organization over the next two days, and a Tropical Cyclone Formation Alert was issued at 150730Z. The first warning (160000Z) on Tropical Depression 14W was based on increased curvature in the spiral convective bands. Then after receipt of several synoptic wind reports of 30 kt (15 m/sec), the cloud system was upgraded to a tropical storm at 161800Z.

The most distinctive characteristic of Gladys was its large size (Figure 3-14-1). Ships and island stations reported an increasingly large area of gale-force winds surrounding the poorly organized circulation. Because of its large size, it was hypothesized that beta drift added a northward component of motion to the westward-oriented track.

The effect of beta drift may have been demonstrated in the fact that Gladys tracked to the right of the dynamic forecast aid, OTCM (Figure 3-14-2). The large displacement of maximum winds far from the cyclone's broad center and the absence of deep convection may have prevented a normal rate of intensification (Weatherford, 1985). For most of its life, Gladys intensified at a slow rate of only 5 kt (3 m/sec) per day, reaching minimal typhoon intensity near Amami-shima, 90 nm (165 km) northeast of Okinawa. The weather station on Amami-shima (WMO 47909) recorded 64 kt (33 m/sec) gradient-level winds and a minimum sea-level pressure of 973 mb as the cyclone center passed within 35 nm (65 km) of the island. After clearing the northern Ryukyu Islands, a fast-moving mid-tropospheric trough induced Gladys to turn north-northwestward. As the trough passed, vertical shear increased on the poleward side of Gladys' cloud mass, and the central pressure of the system began to rise. Reestablishment of the mid-tropospheric subtropical ridge over the Sea of Japan on 22 August prevented recurvature, and Gladys tracked toward the southern coast of Korea. The final warning was issued at 231200Z when the combined effects of increasing shear and land interaction indicated that the circulation was weakening rapidly.

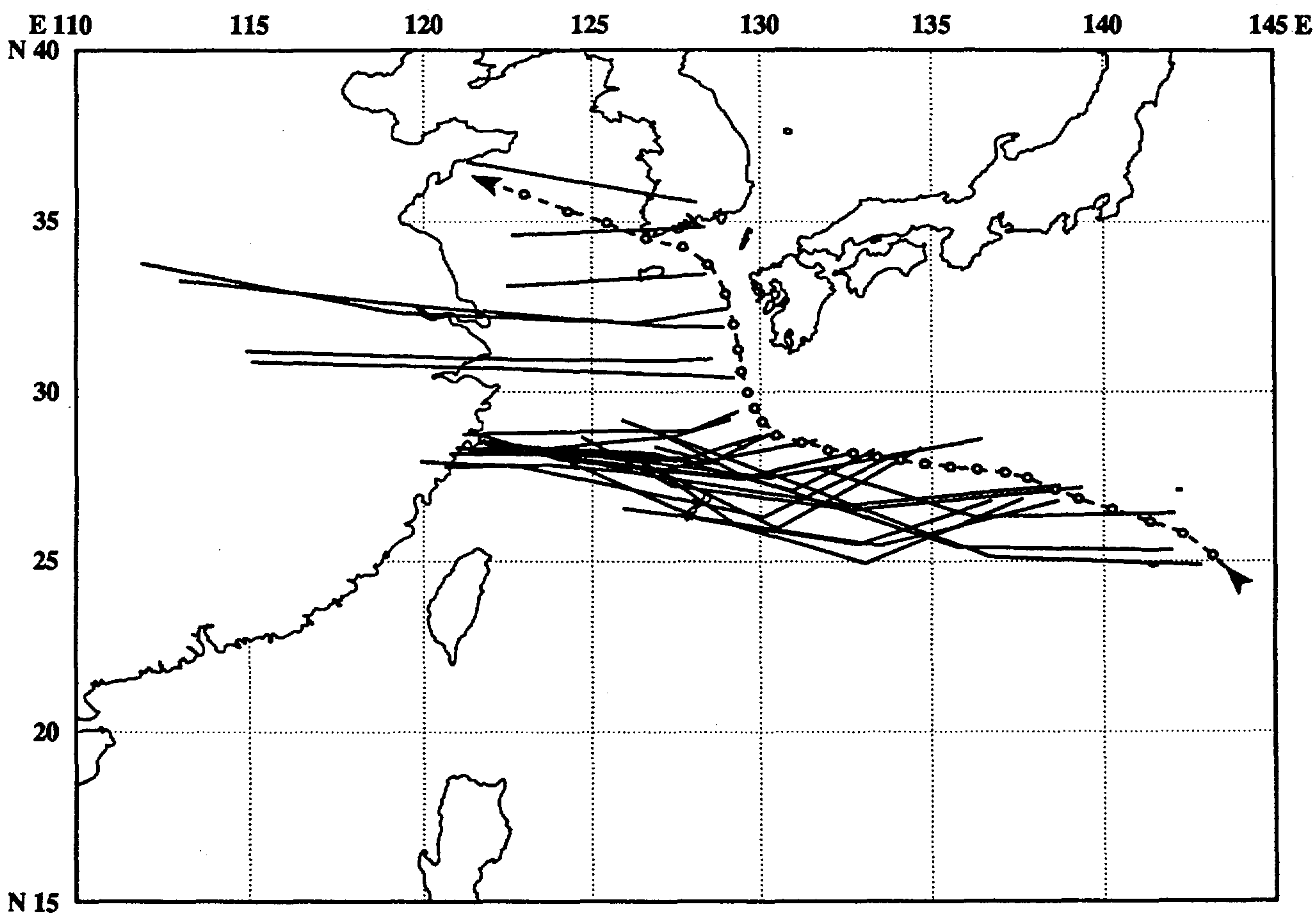


Figure 3-14-2. 160000Z to 231200Z August time series of One-Way (Interactive) Tropical Cyclone Model (OTCM) forecasts versus the official best track. OTCM's poor performance during the entire lifetime of Typhoon Gladys can be partially explained by the beta effect of large tropical cyclones.

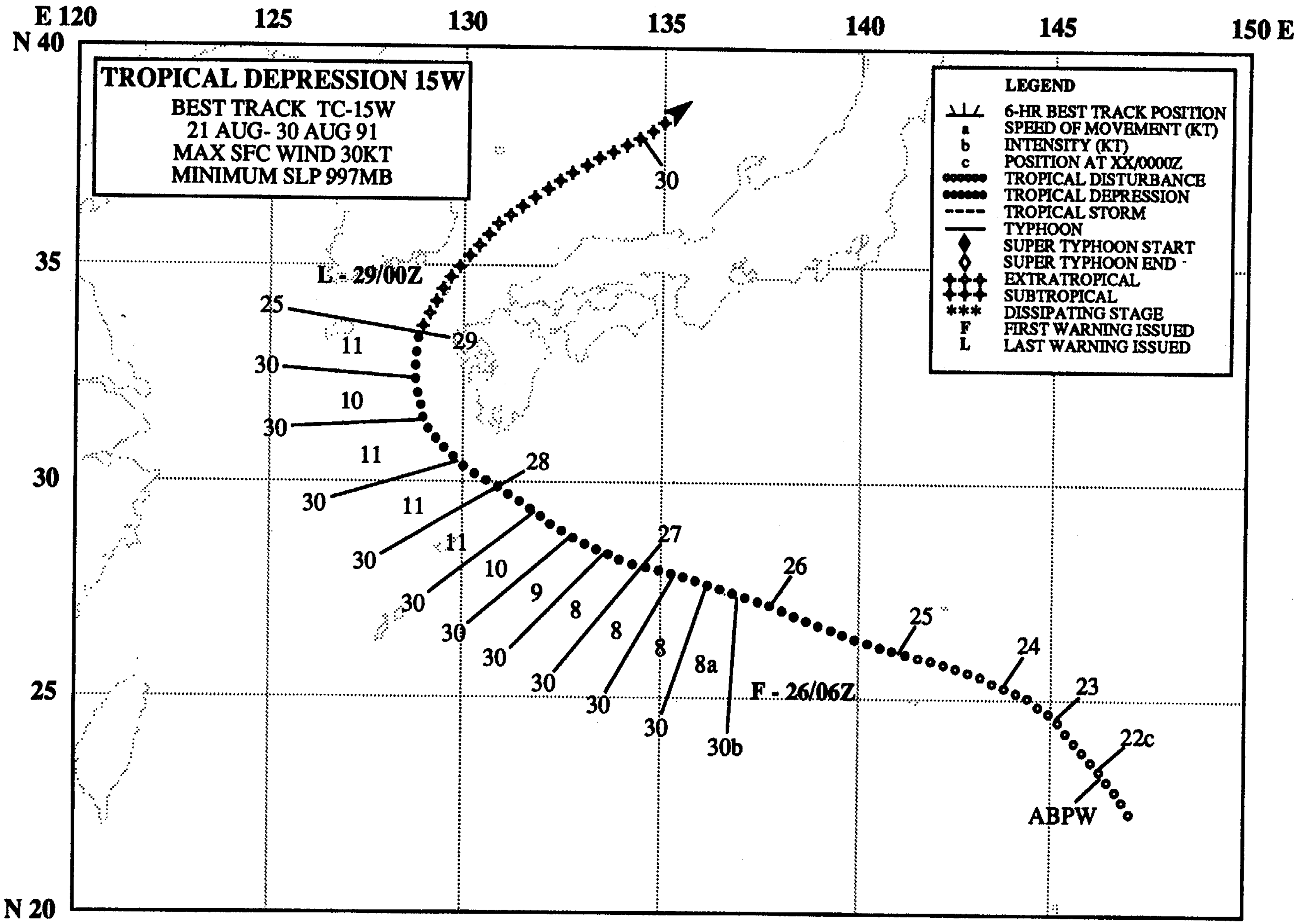
III. FORECAST PERFORMANCE

JTWC motion forecasts of Typhoon Gladys were quite accurate; in fact, only one warning had 72-hour forecast errors larger than 300 nm (555 km). Of note is the fact that JTWC correctly predicted that the cyclone would not recurve, even as it turned north-northwestward near Kyushu. In contrast, other tropical cyclone warning centers in the region predicted that Gladys would recurve through the Korea Strait, between Tsushima and western Kyushu. The divergent forecasts increased the potential for conflicting information to reach operational decision makers in Korea and Japan. During this period, JTWC provided extensive, detailed prognostic reasoning messages which, in conjunction with the warning bulletins and telephone discussions, evaluated the potential for the possible forecast scenarios and helped allay operational concerns.

Intensity forecast performance was poor because Gladys was expected to reach a maximum intensity much greater than 65 kt (33 m/sec). At 161200Z, when the system was only a tropical depression, JTWC predicted it would rapidly intensify to a peak intensity of 120 kt (62 m/sec) in 72 hours, and for the next seven warnings peak winds in excess of 100 kt (51 m/sec) were forecast. As a result, wind errors for the duration of the forecast period were among the highest of the season. In post-analysis, most of the large wind errors could have been avoided if a simple equation relating latitude and peak intensity had been used (Mundell, 1990).

IV. IMPACT

Typhoon Gladys' huge circulation caused record amounts of rainfall in Korea and Japan. South Korea's Disaster Relief Center reported at least 90 people were killed or missing, 62 injured, and 40,000 left homeless. The center estimated property loss at nearly US $45 million. Pusan, Korea's second largest city, received 24 inches (610 mm) of rain in 20 hours and sections along the southeast coast were reported to have received 26 inches (660 mm) during the same period. In addition, Gladys dumped as much as 28 inches (710 mm) of rain on central Japan, triggering landslides which killed 10 people west of Tokyo and flooded at least 1,000 homes.


TROPICAL DEPRESSION 15W
BEST TRACK TC-15W
21 AUG- 30 AUG 91
MAX SFC WIND 30KT
MINIMUM SLP 997MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 120
125
130
135
140
145
150 E
N 40
35
30
25
N 20
L - 29/00Z
F - 26/06Z
ABPW
22c
23
24
25
26
27
28
29
8a
30b

TROPICAL DEPRESSION 15W

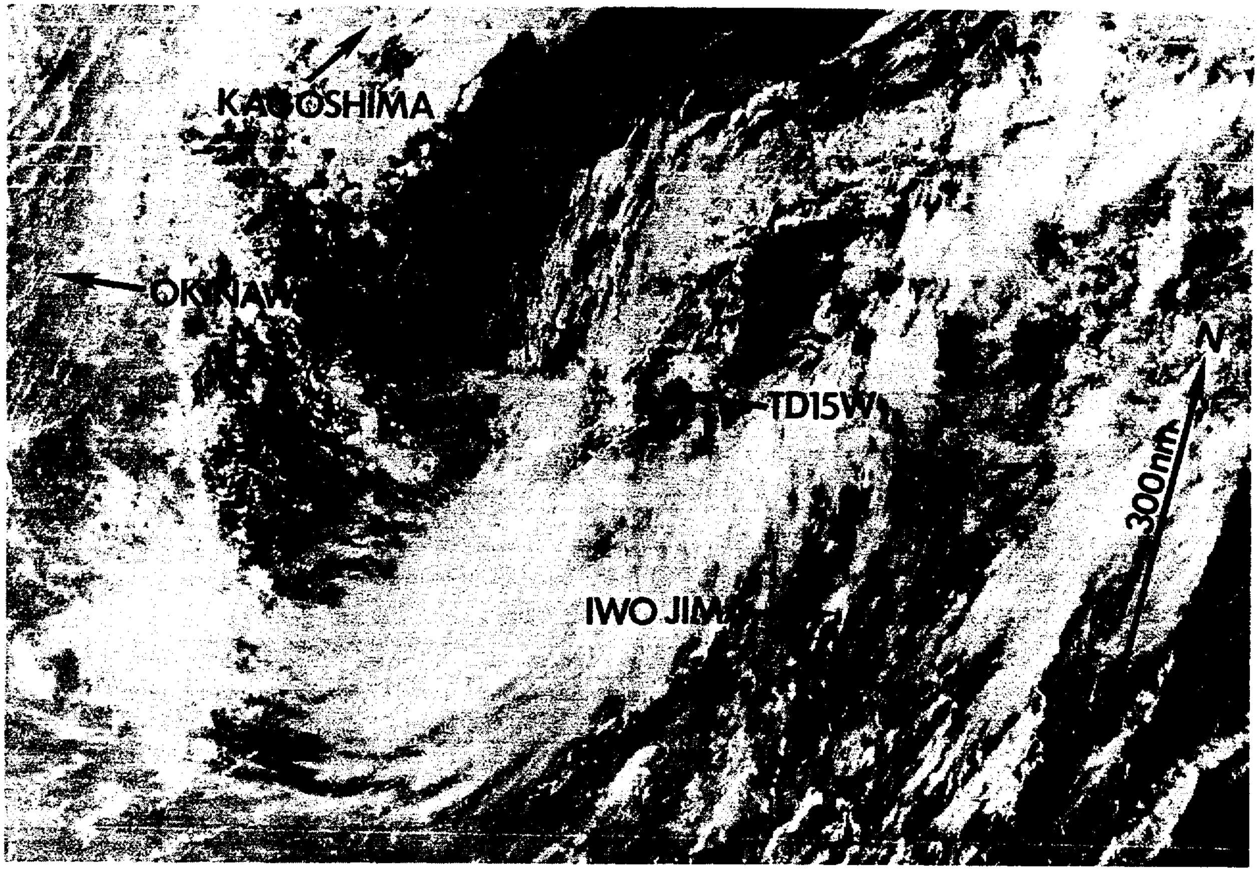
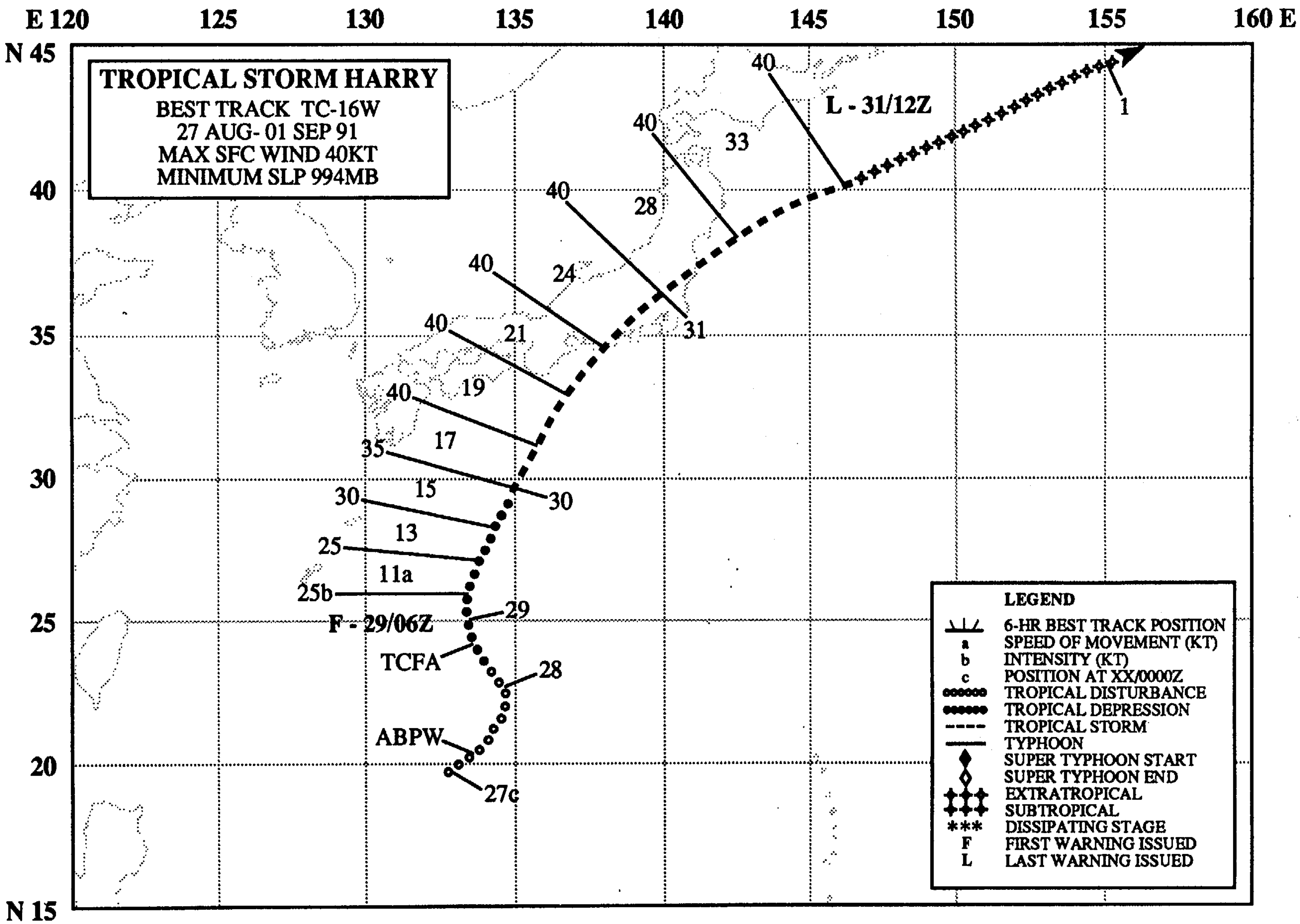


Figure 3-15-1 The well-defined center of Tropical Depression 15W, as seen 6 hours prior to the first warning on the system (252327Z August DMSP visual imagery).

When animated satellite imagery indicated cyclonic turning in an area of deep convection associated with a NSS monsoon gyre (Lander, 1992), a Significant Tropical Weather Advisory was reissued at 212200Z (August) to include the disturbance that was to become Tropical Depression 15W. For the next four days, a single, well-defined circulation center failed to develop. Then, following receipt of a ship report indicating 39 kt (20 m/sec) sustained winds and a surface pressure of 998 mb, the first warning on Tropical Depression 15W was issued at 260600Z. A Tropical Cyclone Formation Alert did not precede the first warning, and the minimal tropical storm intensity indicated by the earlier ship report was discounted due to the continued presence of a shear-type cloud pattern. The depression moved west-northwestward, south of Japan, recurved through a break in the subtropical ridge, and dissipated in the Sea of Japan. It is thought that Tropical Depression 15W did not intensify further because persistent vertical wind shear prevented the development of a persistent central dense overcast.


TROPICAL STORM HARRY
BEST TRACK TC-16W
27 AUG- 01 SEP 91
MAX SFC WIND 40KT
MINIMUM SLP 994MB
E 120
125
130
135
140
145
150
155
160 E
N 45
40
35
30
25
20
N 15
L - 31/12Z
F - 29/06Z
TCFA
ABPW
27c
28
29
30
31
1
11a
25b
LEGEND
6-HR BEST TRACK POSITION
SPEED OF MOVEMENT (KT)
INTENSITY (KT)
POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED

TROPICAL STORM HARRY (16W)

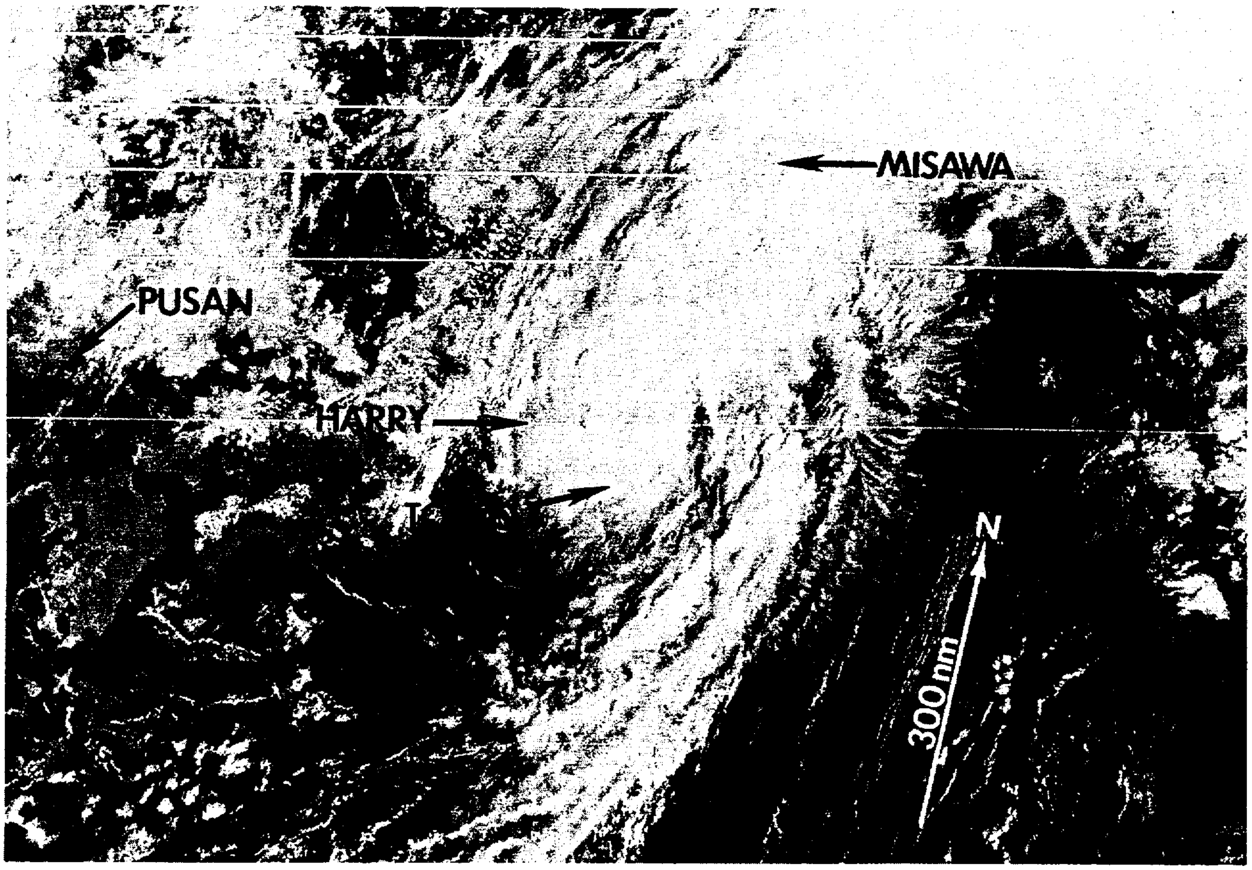
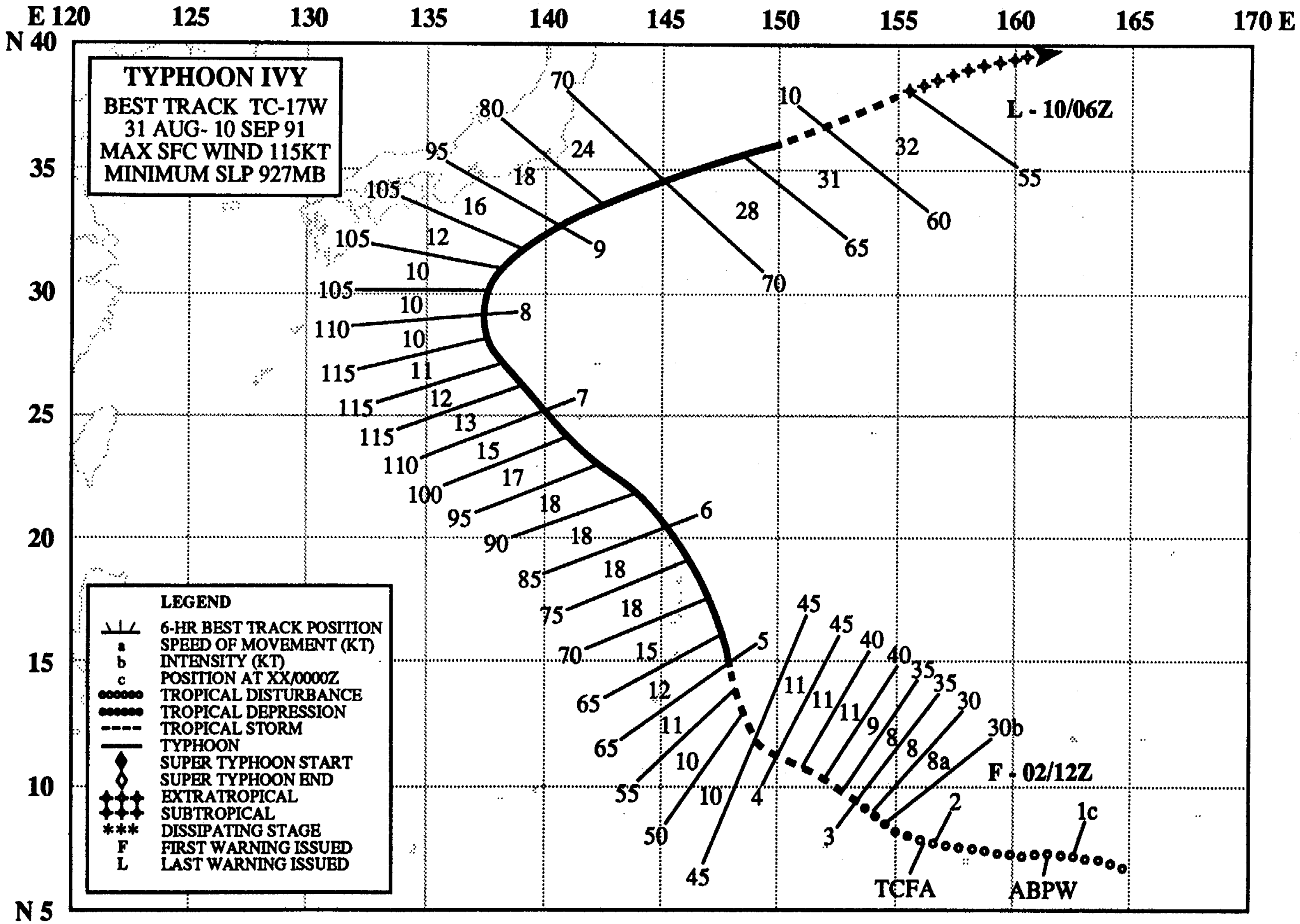


Figure 3-16-1 Tropical Storm Harry crosses the southern coast of Honshu (302320Z August DMSP visual imagery).

Harry was initially detected in the northern Philippine Sea as a poorly organized cyclonic circulation in a NSS monsoon gyre, and was mentioned on the 270600Z August Significant Tropical Weather Advisory. Harry became the last of six tropical cyclones, beginning with Doug (10W) three weeks earlier, to generate within this NSS monsoon gyre. At 281800Z, ship reports of 25 to 30 kt (13 to 15 m/sec) and increased convection on the south side of the circulation prompted the issuance of a Tropical Cyclone Formation Alert. JTWC issued the first warning on Harry at 290600Z. Harry moved northward through a break in the subtropical ridge, recurved and accelerated across the southeastern coast of Honshu near the coastal city of Hamamatsu, which is located 115 nm (215 km) southwest of Tokyo. Weak surface wind reports suggested that the tropical cyclone had no significant impact on the Tokyo metropolitan area. The final warning was issued at 311200Z, when Harry became an extratropical cyclone.



TYPHOON IVY
BEST TRACK TC-17W
31 AUG- 10 SEP 91
MAX SFC WIND 115KT
MINIMUM SLP 927MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 120
125
130
135
140
145
150
155
160
165
170 E
N 40
35
30
25
20
15
10
N 5
L - 10/06Z
F - 02/12Z
TCFA
ABPW

TYPHOON IVY (17W)

I. HIGHLIGHTS

Ivy was the first tropical cyclone to form in the monsoon trough which established itself eastward through the Caroline Islands. Ivy was also the first significant threat of the typhoon season to the Mariana Islands. For 4 days, the tropical cyclone tracked west-northwestward, straight towards Guam, then on 4 September took a sudden, unanticipated turn to the north-northwest and headed for the Northern Marianas and Japan.

II. TRACK AND INTENSITY

Ivy developed in a broad monsoon trough near Kosrae in the eastern Caroline Islands. It was first mentioned on the 010600Z September Significant Tropical Weather Advisory when a consolidated area of convection started to flare up along the trough. As the convection became more organized, a Tropical Cyclone Formation Alert was issued at 020200Z, followed by a warning at 021200Z. Initially, Ivy was difficult to locate precisely as it developed a broad, glaciated central dense overcast. On 4 September, a southwesterly monsoon surge linked up with the cyclone, adding even more diffuse cloudiness (Figure 3-17-1). The surge then sharply pushed the tropical cyclone to the north-northwest, against the western periphery of the subtropical ridge. As Ivy moved northward, it began to rapidly

Figure 3-17-1. Satellite imagery depicts the southwest monsoon cloudiness approaching Ivy while the tropical storm tracks west-northwestward (041214Z September DMSP infrared imagery).

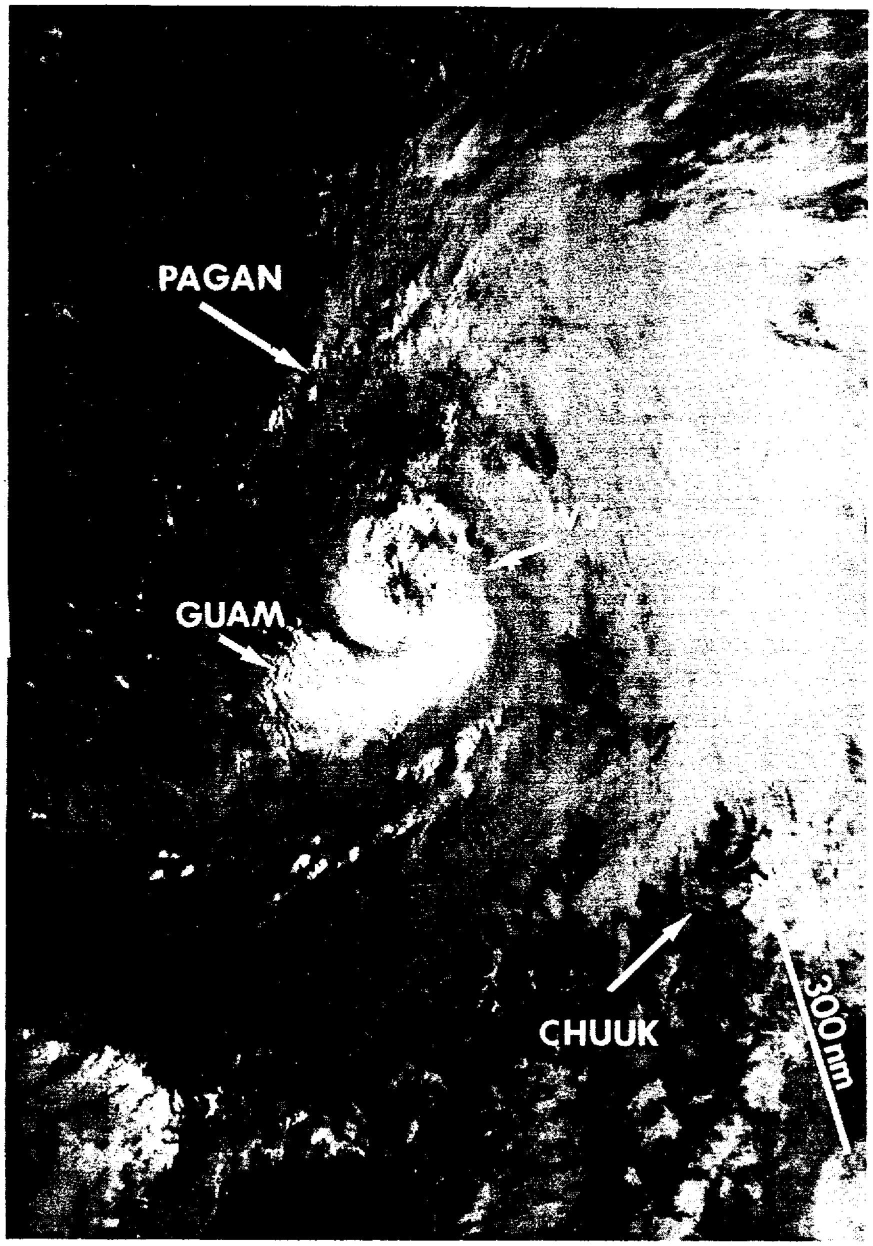


Figure 3-17-2. Satellite imagery 10 hours after Figure 3-17-1 shows Ivy as it reaches typhoon intensity (042242Z September DMSP visual imagery).

intensify, and by 050000Z had formed an eye (Figure 3-17-2). At that time, it was upgraded to typhoon intensity as it passed 130 nm (240 km) east of the islands of Tinian and Saipan in the Commonwealth of the Northern Marianas. The typhoon continued to track north-northwestward towards the axis of the subtropical ridge, and steadily intensified. During 7 September, Typhoon Ivy reached its maximum intensity of 115 kt (59 m/sec), then began to slow down as it made the turn around the ridge axis. Although the vertical shear increased, Ivy entrained most of its inflow from the warm, moist tropical air along its southeastern side. This factor, and its path right on top of the Kuroshio Current, resulted in a more gradual than normal decrease in intensity as the tropical cyclone accelerated south of Japan and transitioned to an extratropical low 600 nm (1110 km) east of Tokyo. The final warning was issued at 100600Z.

III. FORECAST PERFORMANCE

Initially, Ivy was on a westward course, then turned abruptly towards the north-northwest as it intensified. Before this turn, all JTWC forecasts reflected a west-northwest track under the subtropical ridge (Figure 3-17-3). On 3 September forecaster confidence was high that the ridge to the north of Ivy would hold and the track would be near Guam. Guam and Rota went into Condition of Readiness 2, as Ivy moved closer to the islands, and JTWC expected the system to reach typhoon intensity as it hit. The dynamic guidance was in agreement with the west-northwest track until the NOGAPS prognostic

series at 040000Z. Then, the NOGAPS model indicated a rapid breakdown of the ridge, possibly in response to the southwesterly monsoon surge. Satellite data indicated that the tropical cyclone had turned, but an early radar fix still suggested west-northwestward motion. Once it was determined by subsequent radar information that Ivy was, in fact, moving away from the area, JTWC recommended that Tinian and Saipan increase their condition of readiness from 3 to 2. The Center then adopted a north-northwestward track that verified well as the system moved northward towards Japan.

The intensity forecasts for Ivy's early stages were initially too high due to a slower than normal rate of intensification. The forecast intensities verified well as the system recurved south of Japan.

IV. IMPACT

Rough seas churned up by Ivy's passage were responsible for one drowning on the island of Saipan. While Typhoon Ivy passed just to the east of Pagan (WMO 91222)(Figure 3-17-4) and Agrihan Islands in the Northern Marianas, no injuries and only minor damage were reported by the 13 residents of Agrihan. As Ivy paralleled the southern coast of Honshu, one fisherman was killed and four others were reported missing. Later, as the typhoon passed the southeastern tip of Honshu, Tokyo and the surrounding areas experienced high winds and heavy rains which disrupted ground and air transportation and left four people injured. Additional reports of damage in Japan included over 200 landslides and 733 flooded homes.

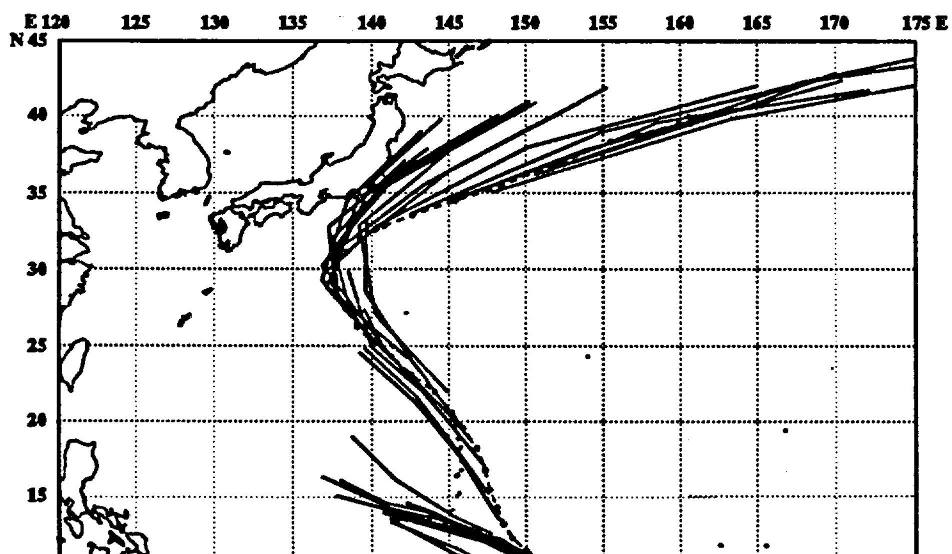
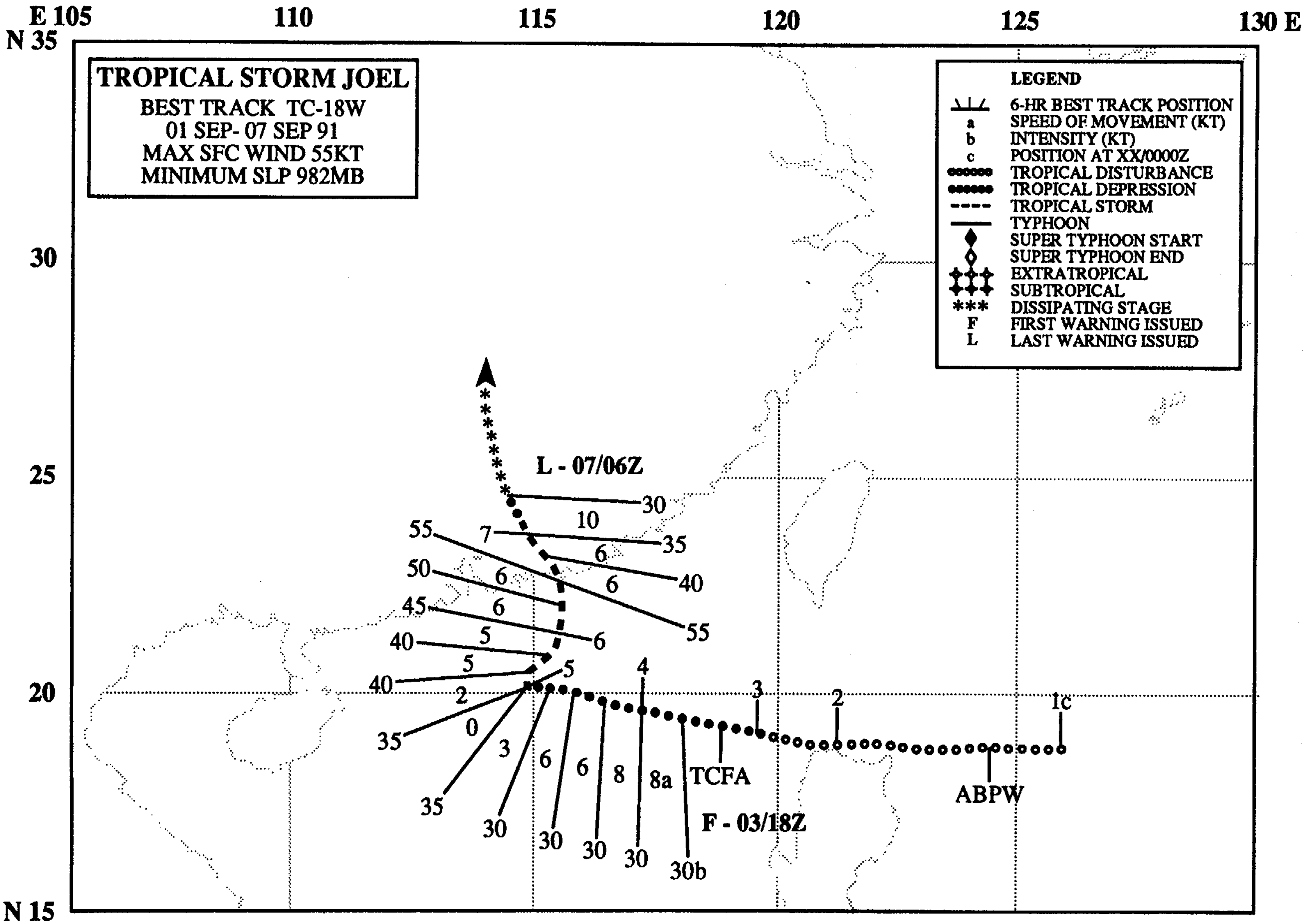


Figure 3-17-3. A comparison of JTWC official forecast positions with Ivy's verifying final best track positions.

Figure 3-17-4. Intermittent wind reports from the Pagan Island (WMO 91222) Automatic Meteorological Observing Station reflect Ivy's passage to the east. The closest point of approach (CPA), 45 nm (85 km), occurred on 5 September.


TROPICAL STORM JOEL
BEST TRACK TC-18W
01 SEP- 07 SEP 91
MAX SFC WIND 55KT
MINIMUM SLP 982MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 105
110
115
120
125
130 E
N 35
30
25
20
N 15
L - 07/06Z
F - 03/18Z
TCFA
ABPW
8a
30b
1c

TROPICAL STORM JOEL (18W)

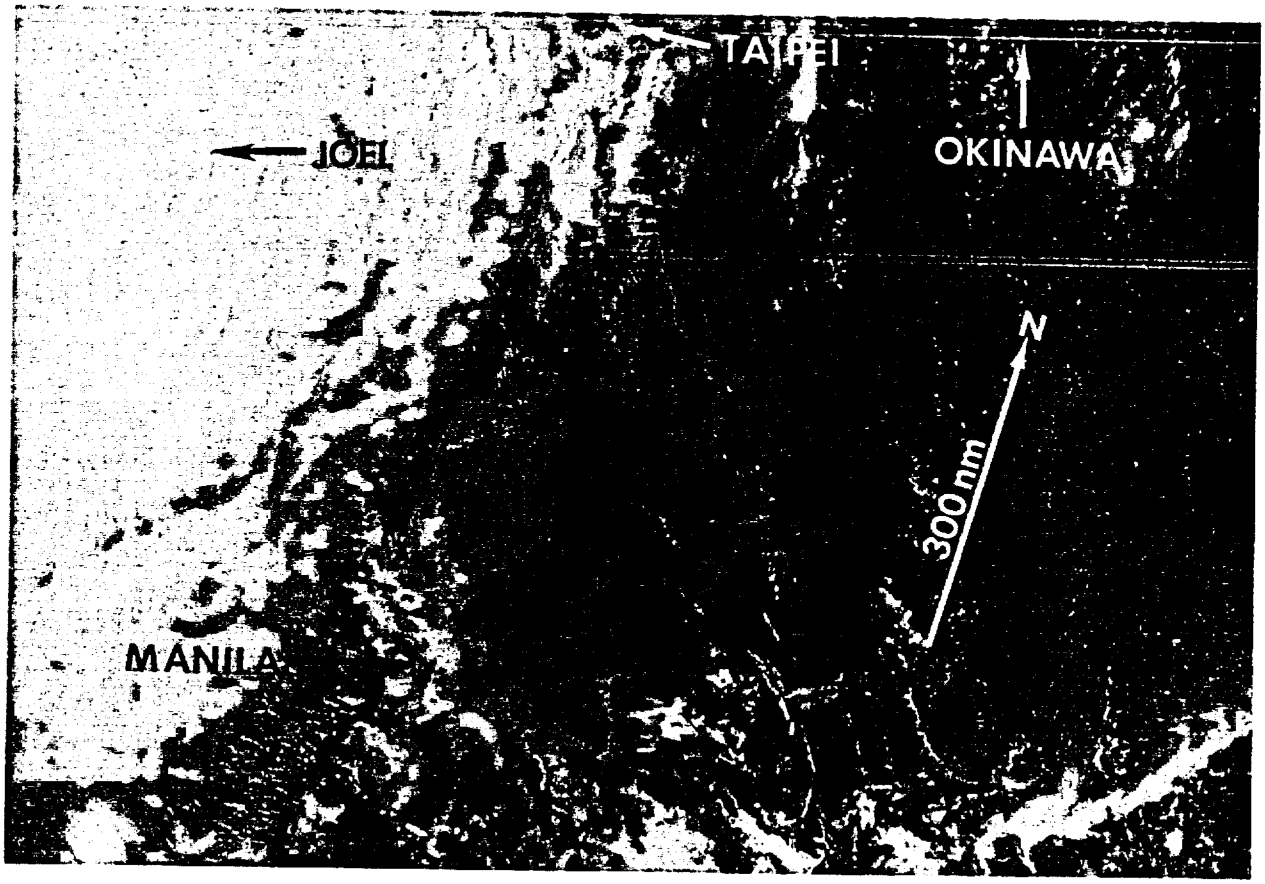
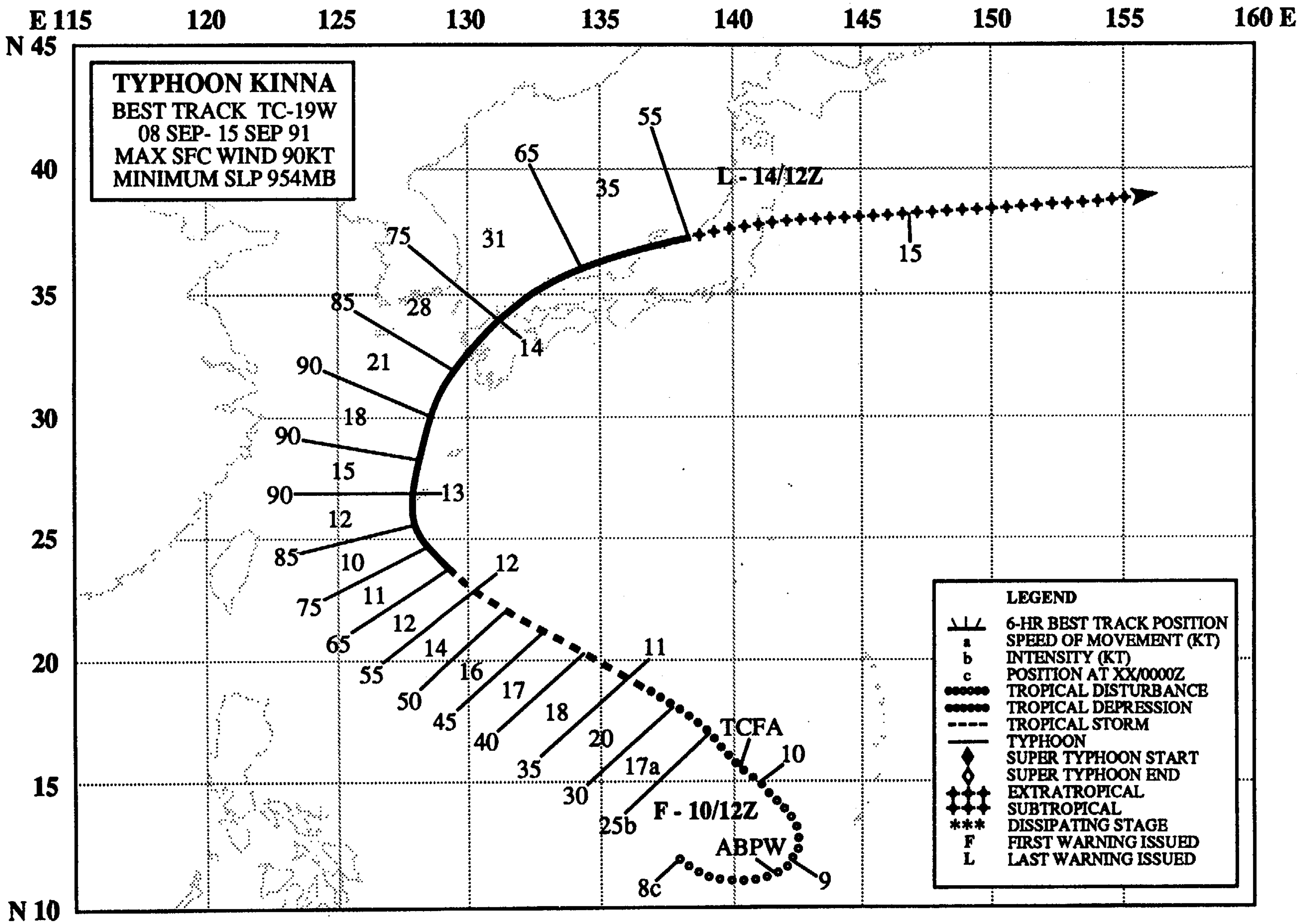


Figure 3-18-1 The cloud shield of Tropical Storm Joel covers much of the South China Sea just prior to landfall (060033Z September DMSP visual imagery).

Joel's poorly organized, but persistent, convection was first mentioned on the 010600Z September Significant Tropical Weather Advisory. Falling surface pressures along with increasing cloud amount and organization prompted a Tropical Cyclone Formation Alert at 030930Z. The first warning followed, valid at 031800Z. The subsequent upgrade to tropical storm intensity at 041200Z, appeared, in post analysis, to be 12 hours premature. As Joel tracked westward in the South China Sea, a southwesterly monsoon surge enhanced the deep convection near the cyclone's center. Then the surge, in conjunction with mid-tropospheric troughing to the north which interrupted the steering flow, caused Joel to come to a halt. After little or no movement for six hours, the tropical cyclone slowly moved northward towards the break in the ridge and made landfall at 161200Z, 70 nm (130 km) east of Hong Kong. Aided by convergent low-level wind flow in the coastal zone, Tropical Storm Joel reached its maximum intensity of 55 kt (28 m/sec) before moving onshore and dissipating over the mountains inland.


TYPHOON KINNA
BEST TRACK TC-19W
08 SEP- 15 SEP 91
MAX SFC WIND 90KT
MINIMUM SLP 954MB
E 115
120
125
130
135
140
145
150
155
160 E
N 45
40
35
30
25
20
15
N 10
L - 14/12Z
F - 10/12Z
TCFA
ABPW
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TYPHOON KINNA (19W)

I. HIGHLIGHTS

Kinna was the most destructive tropical cyclone to strike Okinawa since 1987, and the first typhoon to pass directly across the island since Vera in 1986. The typhoon also passed directly across Sasebo, Japan, and caused extensive damage on Kyushu and Honshu as it raced northeastward after recurvature. The exceptionally accurate forecasts of the path taken by Typhoon Kinna provided more than ample lead time for disaster preparation at key DOD installations.

II. TRACK AND INTENSITY

Kinna formed in the western Caroline Islands in the monsoon trough which extended across the Philippine Sea in early September. On 8 September, analysis of synoptic data revealed that a circulation was developing southwest of Guam. When satellite imagery showed an increase in convection near the circulation center, the Significant Tropical Weather Advisory was reissued at 081800Z to include the disturbance as an area with fair potential for tropical cyclone development. As the area of deep convection moved west of Guam and showed signs of increased organization, a Tropical Cyclone Formation Alert was issued at 100400Z. The first warning on Tropical Depression 19W was at 101200Z. Kinna's northwestward motion on 10 and 11 September was a reflection of a weak subtropical ridge north of the system which extended along 25°N latitude. The weak ridge allowed Kinna (Figure 3-19-1) to gain latitude as it intensified. At 120600Z, the presence of a poorly

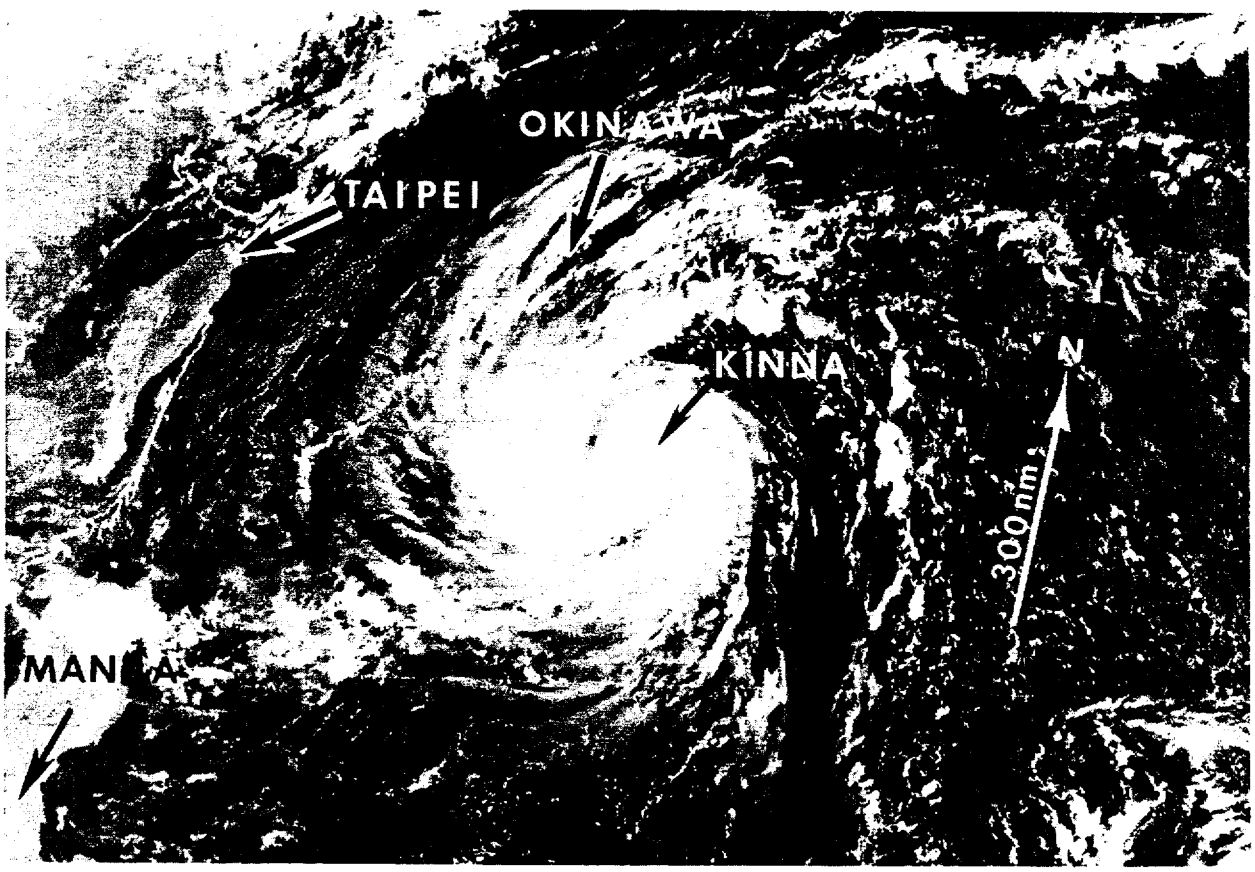


Figure 3-19-1. Typhoon Kinna intensifies as it heads for Okinawa, Japan (120004Z September DMSP visual imagery).

defined eye in the central dense overcast prompted an upgrade of Kinna to typhoon intensity.

On 12 September, a mid-tropospheric trough deepened in the East China Sea and split the weak ridge near 125°E longitude. In response, Typhoon Kinna turned northward toward the break in the ridge and tracked across Okinawa. The eye crossed densely populated southern Okinawa, with a minimum surface pressure of 958 mb recorded at Kadena AB (WMO 47931) (Figure 3-19-2). The wind recorder chart from Futenma MCAS (WMO 47933) graphically describes the three hour passage of the eye across the station (Figure 3-19-3). On Okinawa, the peak wind gust observed at Futenma MCAS (WMO 47933) was 96 kt (49 m/sec) with 82 kt (42 m/sec) at Kadena AB, and 95 kt (49 m/sec) at Naha. After recurvature, Kinna accelerated north-northeastward toward Kyushu and maintained its intensity. It's eye wall passed over the cities of Nagasaki and Sasebo on Kyushu on the 13th, with peak wind gusts of 100 kt (51 m/sec) recorded at Metabaru (WMO 47860), located 45 nm (85 km) northeast of Nagasaki. Kinna continued to accelerate due to deep mid-tropospheric westerly flow, and rapidly transitioned into an extratropical low as it tracked along the northern coast of Honshu. The final warning was issued at 141200Z.

III. FORECAST PERFORMANCE

After opting for a recurvature track on the third warning at 111800Z, forecasters correctly identified the major changes that would occur in the subtropical ridge as the short wave trough moved off of Asia. JTWC forecasters accurately predicted that Kinna would strike Okinawa, Sasebo (on Kyushu), and later skirt the northern coast of Honshu. Starting with the fourth warning issued at 120000Z, JTWC stayed with this forecast track (Figure 3-19-4). As a consequence, JTWC's performance was substantially better than its objective aids, primarily because the forecast guidance was much slower than Kinna's actual forward motion. Forecasters relied heavily on persistence for speed guidance as Kinna approached the point of recurvature and then began to accelerate. Although JTWC had a good handle on the path the typhoon would take, the greatest forecast problem was the amount of acceleration to expect as Kinna underwent extratropical transition.

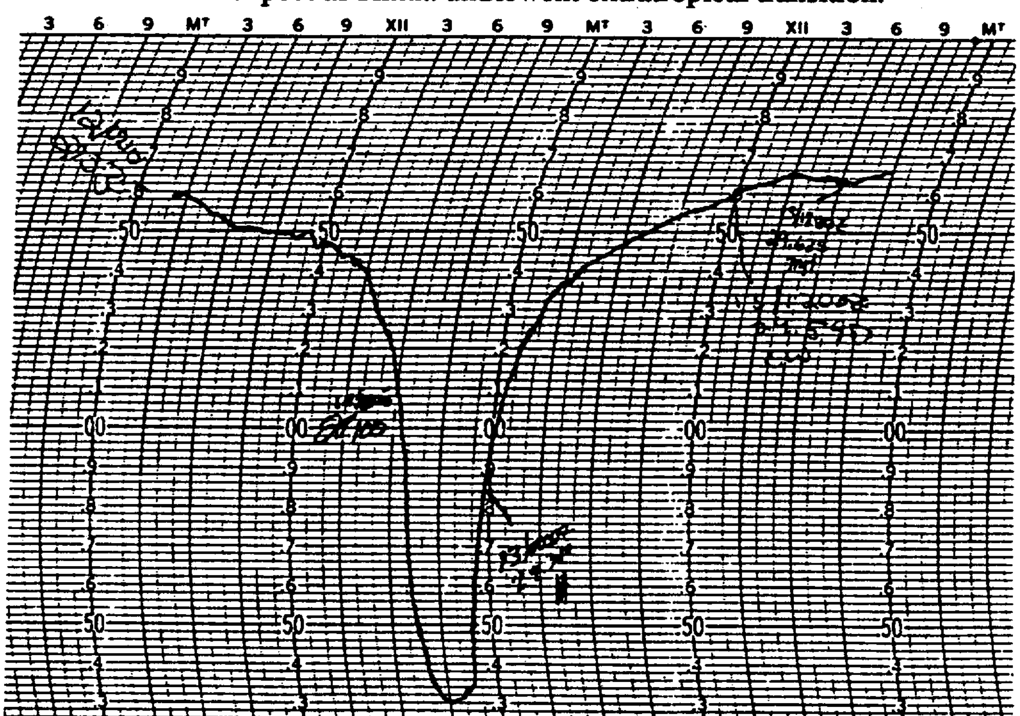


Figure 3-19-2. Microbarograph trace of surface pressure in inches of mercury recorded at Kadena AB, Japan during Kinna's passage. The minimum 28.30 at 122100Z September equates to 958 mb.

IV. IMPACT

As a result of the accurate warnings, preparations to limit the amount of damage on Okinawa and to sortie ships in the path of the typhoon were made well in advance of Kinna's approach. Despite the strong winds, damage to military installations on Okinawa and at Sasebo was minimal. Nine deaths and 65 injuries were attributed to Typhoon Kinna in Japan and on Okinawa. Most of the damage occurred on Kyushu near Nagasaki and on western Honshu. Press reports indicated 158 houses collapsed, more than 2,733 were flooded, and nearly 500,000 households were without power. The eight inches of rain which fell on Okinawa in a 24-hour period during Kinna's passage eased the island's drought conditions, and temporarily eliminated water rationing.

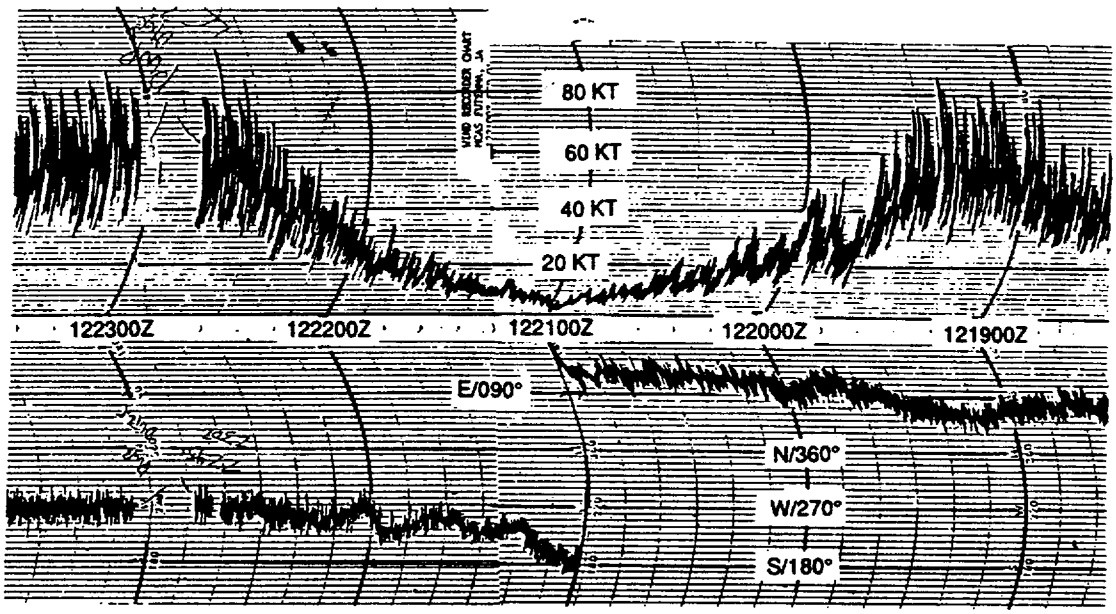


Figure 3-19-3. Futenma MCAS (WMO 47933), Okinawa, Japan, wind recorder chart reflects the three hour passage of Kinna's eye across the station.

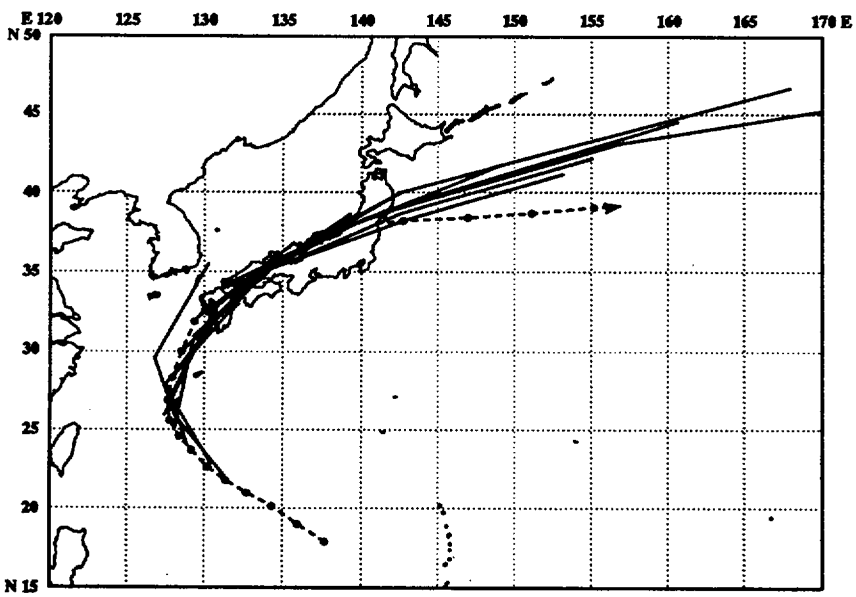
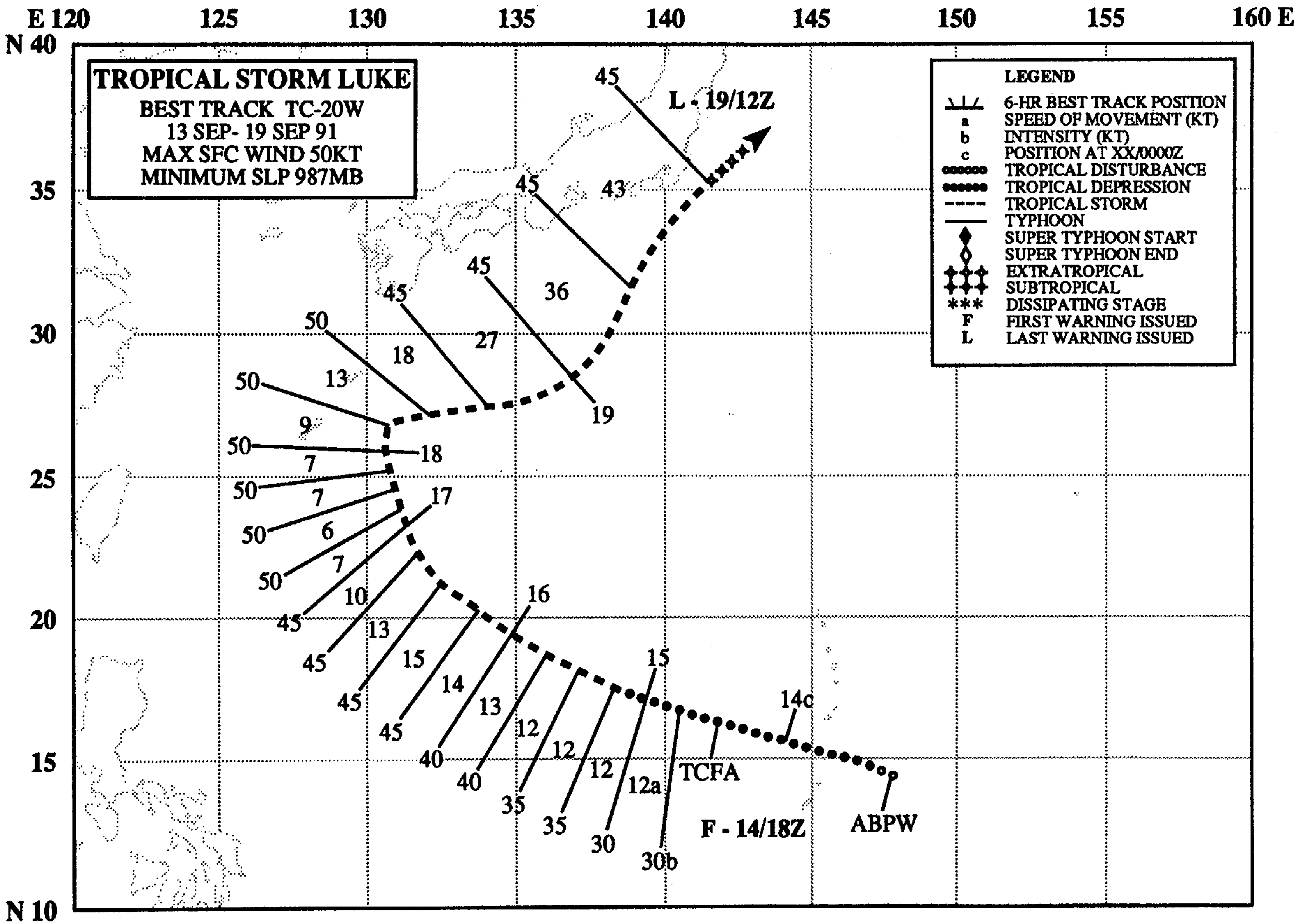


Figure 3-19-4. Comparison of JTWC forecasts issued from 120000Z to 140000Z September to the best track of Typhoon Kinna. JTWC forecasts correctly predicted the eventual path of Kinna, but were slow to predict Kinna's acceleration across Japan.


TROPICAL STORM LUKE
BEST TRACK TC-20W
13 SEP- 19 SEP 91
MAX SFC WIND 50KT
MINIMUM SLP 987MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 120
125
130
135
140
145
150
155
160 E
N 40
35
30
25
20
15
N 10
L - 19/12Z
F - 14/18Z
TCFA
ABPW
14c
12a
30b

TROPICAL STORM LUKE (20W)

I. HIGHLIGHTS

Tropical Storm Luke (20W), a broad monsoonal cyclone, had the largest initial position errors of the season. Its unusual recurvature track was the result of an extension of the mid-latitude westerlies deep into the tropics in mid-September, which temporarily broke down the subtropical ridge in the western Pacific.

II. TRACK AND INTENSITY

Luke formed from a disturbance that passed near Saipan late on 14 September. It was initially mentioned on the 130600Z Significant Tropical Weather Advisory. As the disturbance tracked west-northwestward, improved upper-level anticyclonic outflow and sea-level pressure falls of 3 mb led to the issuance of a Tropical Cyclone Formation Alert at 141130Z. At 141800Z, the first warning on Tropical Depression 20W was issued when the synoptic data indicated that a closed circulation had developed. At this time, Luke was a monsoon depression, with a ring of 30 kt (15 m/sec) winds around a large central area of light and variable winds. The cyclone continued to slowly intensify over the next 48 hours as it tracked west-northwestward. On 17 September, satellite imagery indicated that the circulation had lost organization, and that it appeared to be moving westward, but on 18 September an exposed low-level circulation revealed that the tropical storm had, in fact, turned north-northwestward (Figure 3-20-1). Shortly afterward, Luke made another sharp change in direction to the east as a mid-tropospheric trough brought westerly winds deep into the tropics and caused the subtropical ridge,

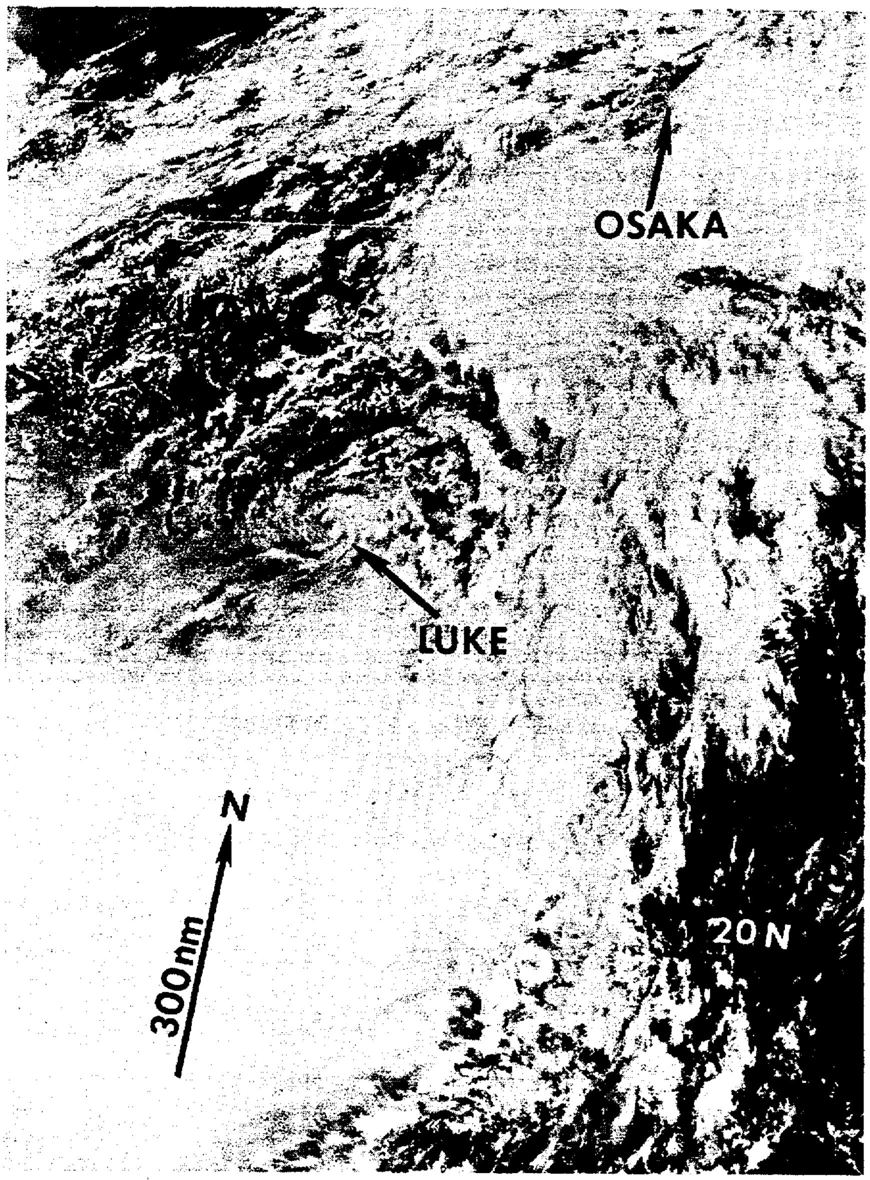
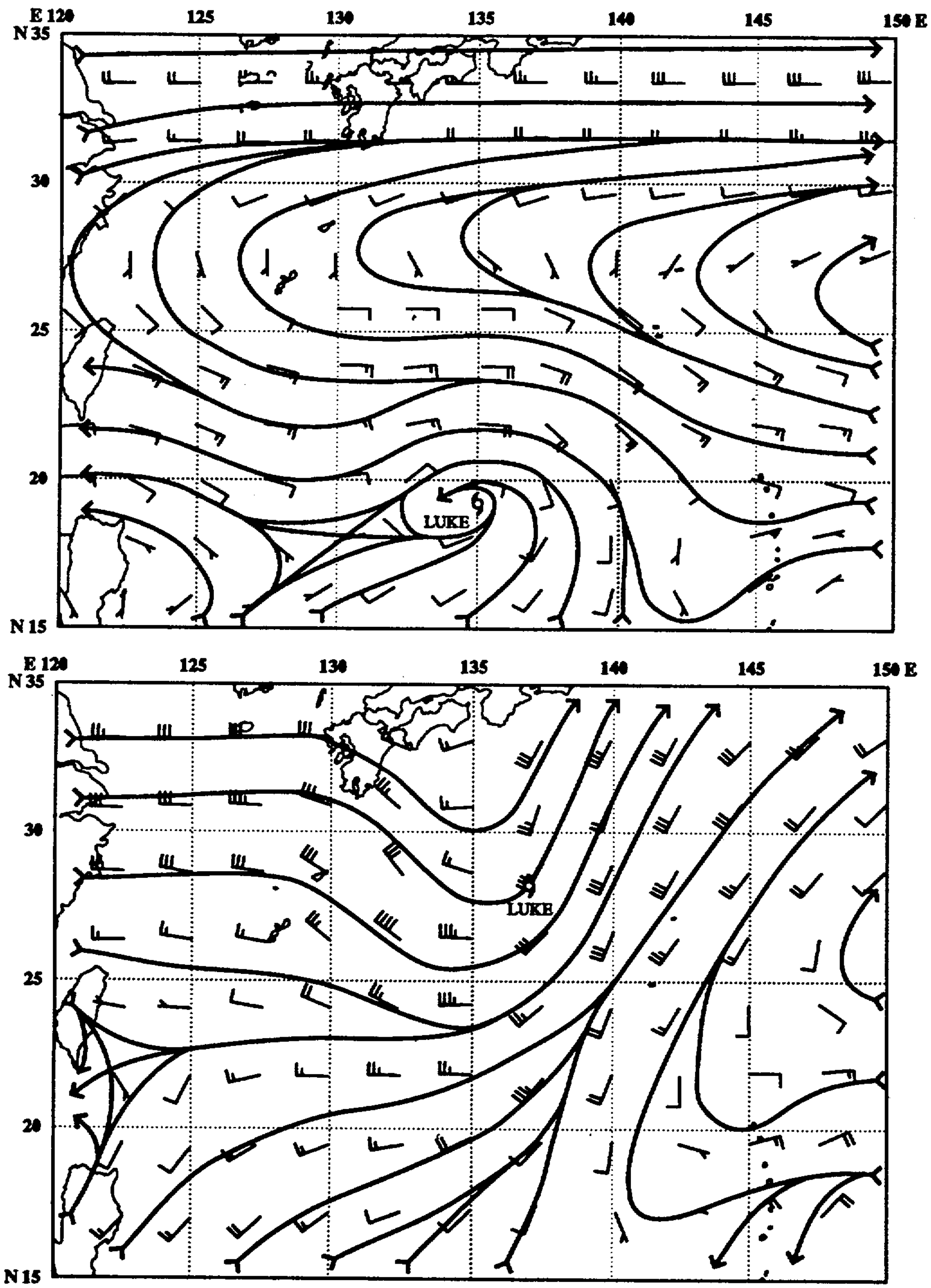


Figure 3-20-1. The exposed low-level center of Tropical Storm Luke as it makes its closest point of approach 160 nm (295 km) east of Okinawa (172336Z September DMSP visual imagery).

which had been holding the system to a westward track, to recede eastward (Figure 3-20-2). Meanwhile, the vertical wind shear between Luke and the westerlies scrambled the cloud pattern during the evening hours. This left JTWC attempting to extrapolate a track to the north-northwest, while the obscured low-level circulation of Luke (Figure 3-20-3) was actually accelerating northeastward and transitioning into an extratropical cyclone. This misinterpretation caused JTWC forecasters to issue an unnecessary Tropical Cyclone Formation Alert at 181500Z on a peripheral convective area. The alert was canceled at 190400Z. The final warning on Tropical Storm Luke was issued at 191200Z.

III. FORECAST PERFORMANCE



(a)

(b)

Figure 3-20-2. NOGAPS Deep-layer mean analyses at (a) 160000Z and (b) 190000Z September. Note the dramatic change in the extent of the subtropical ridge axis during the 72-hour period as mid-latitude westerlies associated with a passing trough penetrated unusually far equatorward.

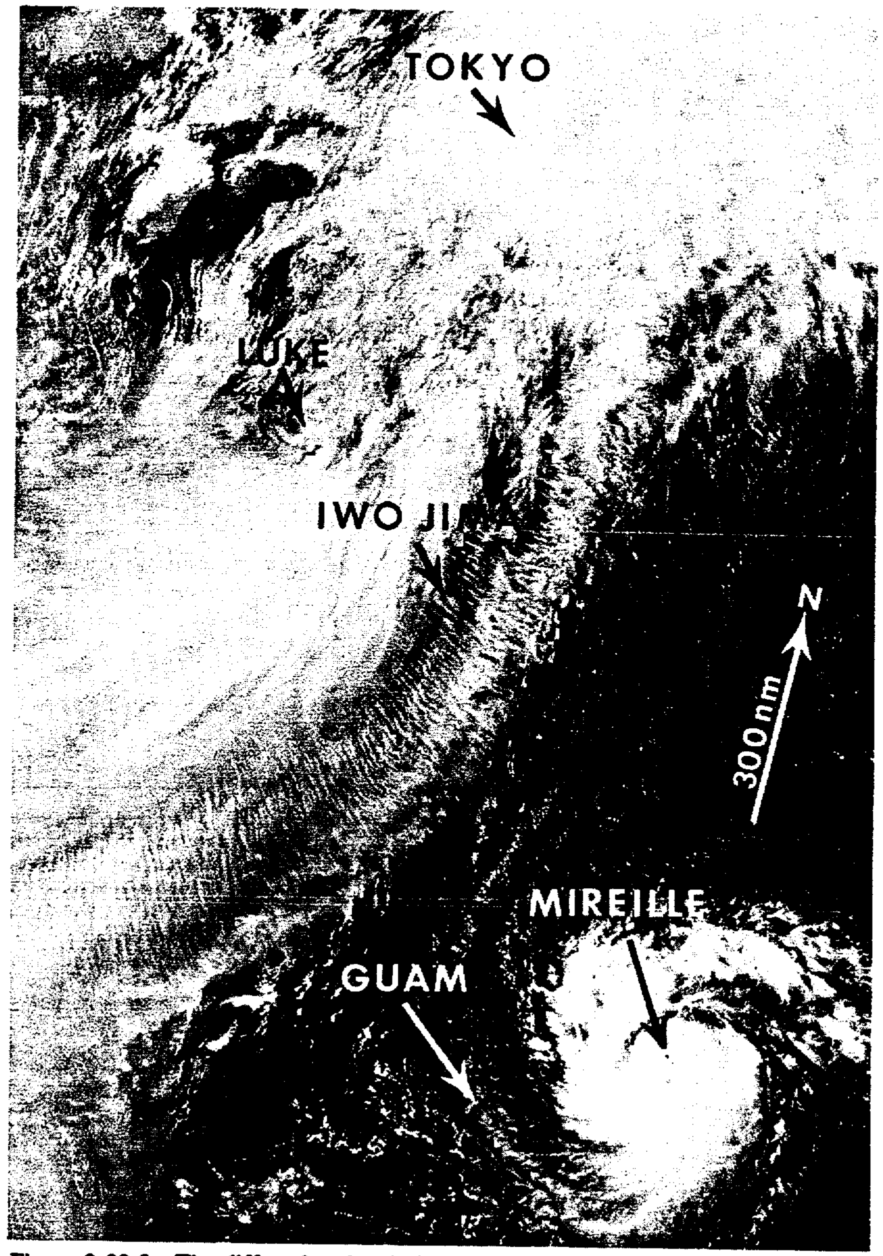
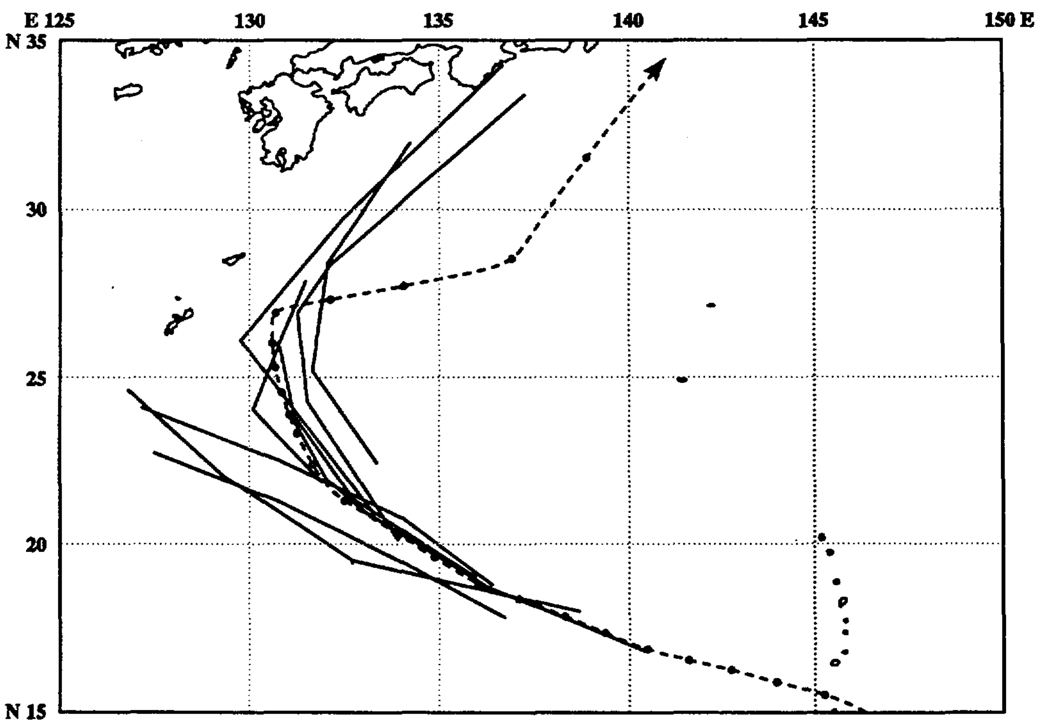


Figure 3-20-3. The diffuse low-level circulation and extensive area of convection associated with Luke as it undergoes extratropical transition south of Honshu. Typhoon Mireille (21W) appears at the lower right of the picture (182314Z September DMSP visual imagery).

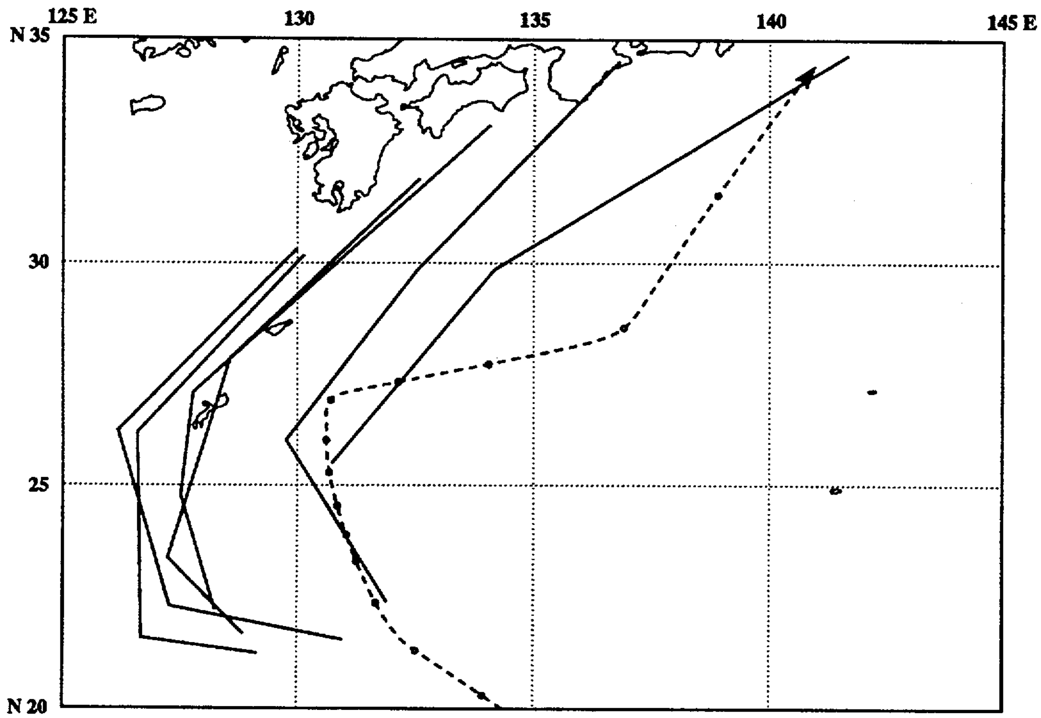
On 17 and 18 September, uncertainty over the initial warning positions of Tropical Storm Luke underscored the limitations that can occur in locating a poorly defined cloud system center from only infrared satellite images, and the effect these limitations can have on JTWC warnings. A comparison of JTWC forecasts with the verifying best track graphically illustrates where erroneous initial positions misled JTWC forecasts (Figure 3-20-4). Until 161800Z, JTWC warnings were in agreement that Luke would recurve east of Okinawa and head toward Honshu ahead of an approaching mid-tropospheric trough. These warnings accurately represented the future path of the cyclone and had low forecast errors. Starting at 170000Z, forecasters adopted the scenario that the system was moving westward, causing the recurvature forecast tracks to be adjusted further westward, threatening Okinawa. A relocation of the warning position at 180000Z was too late to prevent the evacuation of some aircraft from Kadena AB on Okinawa. Another major relocation of the cyclone occurred at 190000Z because of the significant track change which occurred during the nighttime. Using infrared imagery, satellite analysts had a challenging task locating the poorly defined circulation center residing beneath a dense cloud shield. In turn, JTWC's extrapolation of the perceived short-term motion resulted in large forecast errors.

IV. IMPACT

Although Luke did not attain typhoon intensity, its broad area of gale-force winds and torrential rains affected large portions of the western Pacific. On 17 September, JTWC forecasts resulted in the unnecessary evacuation of aircraft stationed at Kadena AB, costing an estimated $300,000. Later, on 19 September, record rainfall from Luke caused extensive flooding in central Japan, resulting in the deaths of at least 8, with 10 other people reported missing and damage to 28,000 homes.



(a)



(b)

(c)

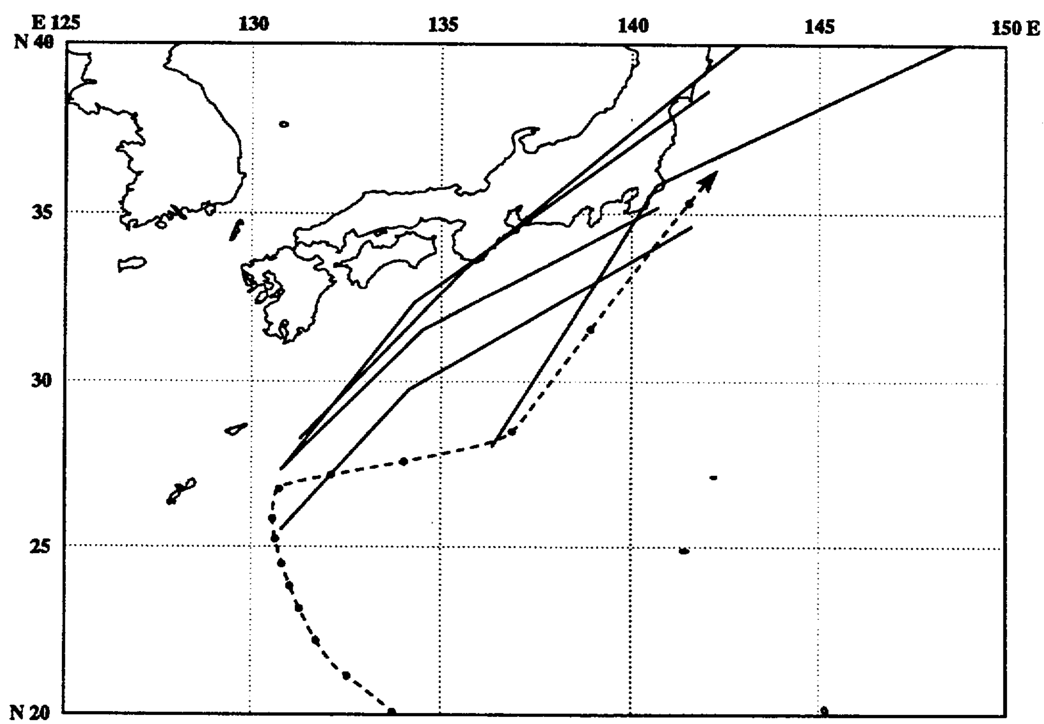
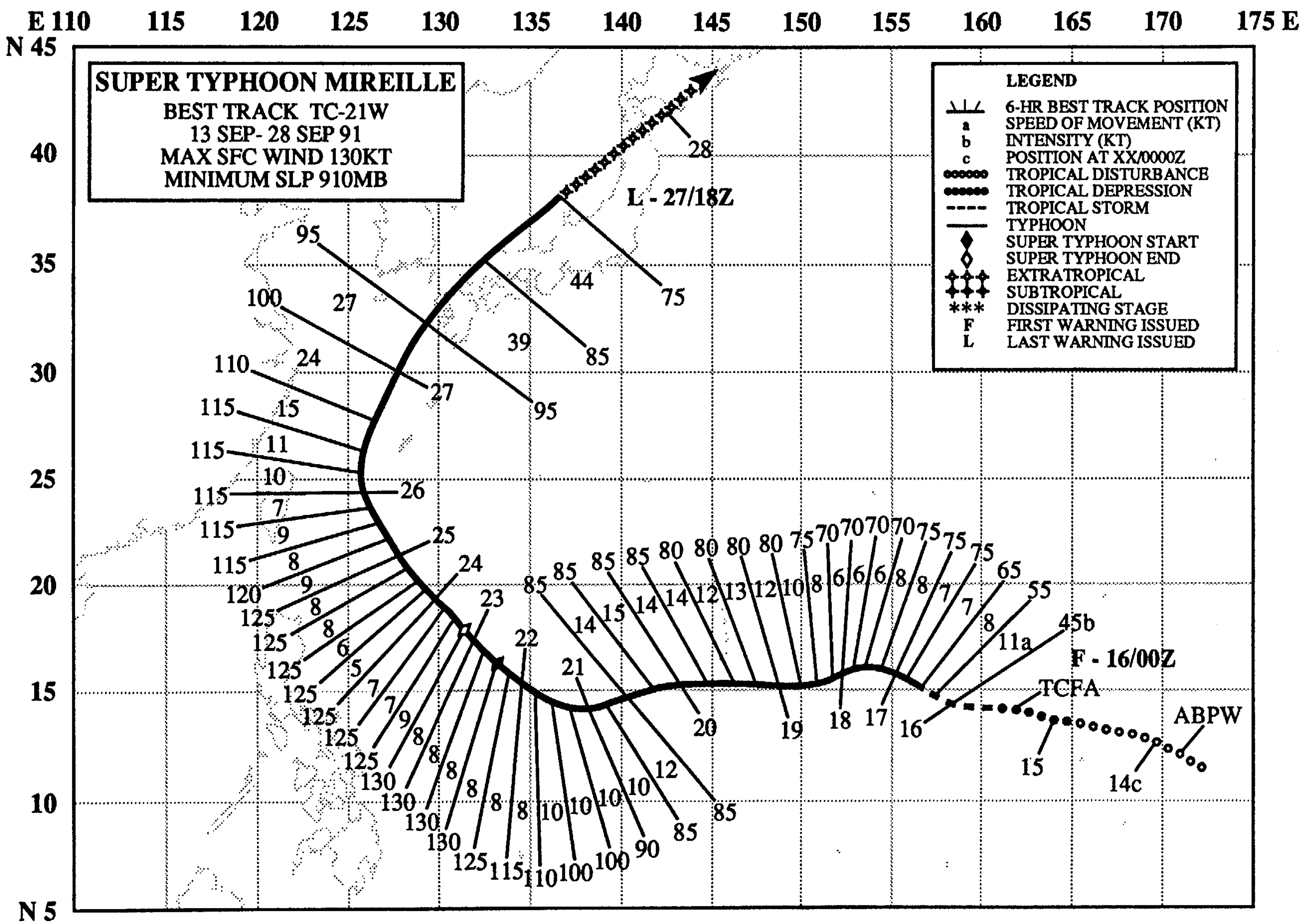


Figure 3-20-4. Comparison of the oficial forecast to the final best track for (a) 141800Z to 161800Z, (b) 161800Z to 180000Z, and (c) 180600Z to 190000Z September.


SUPER TYPHOON MIREILLE
BEST TRACK TC-21W
13 SEP- 28 SEP 91
MAX SFC WIND 130KT
MINIMUM SLP 910MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 110
115
120
125
130
135
140
145
150
155
160
165
170
175 E
N 45
40
35
30
25
20
15
10
N 5
L - 27/18Z
F - 16/00Z
TCFA
ABPW
45b
11a
14c

SUPER TYPHOON MIREILLE (21W)

I. HIGHLIGHTS

The second super typhoon in the Northwest Pacific of the year, Mireille became the worst storm to strike Japan in three decades. Mireille outgrew its early midget size and reached super typhoon intensity several days before threatening Okinawa. Recurving just to the southwest of Okinawa, the typhoon accelerated, cutting a path across western Kyushu and Honshu. Then over the Sea of Japan, Mireille transitioned into an intense extratropical cyclone which slammed into northern Honshu. Mireille was part of a three storm outbreak in September - first with Tropical Storm Luke (20W) and Typhoon Nat (22W), and later with Typhoons Nat and Orchid (23W).

II. TRACK AND INTENSITY

Mireille was first detected as a poorly organized area of cloudiness in the monsoon trough over the southern Marshall Islands. The disturbance was first mentioned on the 130600Z Significant Tropical Weather Advisory. An increase in the amount of the tropical disturbance's deep convection prompted a Tropical Cyclone Formation Alert at 151200Z. Assuming normal development, forecasters issued the first warning for a 30 kt (15 m/sec) system at 160000Z. However, this was not to be a normal system. This was reflected in the 160600Z warning which upgraded the intensity to 45 kt (23 m/sec) and identified the system as very compact and rapidly intensifying. For several days the tropical system drifted to the west-northwest under the influence of the subtropical ridge. On the evening of 17 September, Mireille began to track to the west-southwest, creating some concern that it would target Guam, but 24 hours later the typhoon acquired a westward track and passed 12 nm (20 km) north of Saipan on 19 September as a midget typhoon. Then, on 21 September, the typhoon (Figure 3-21-1) began tracking to the northwest along the southwestern periphery of the ridge, and began interacting with Typhoon Nat (22W). This binary interaction (Figure 3-21-2) resulted in the temporary capture of the smaller typhoon, Nat, and its subsequent movement southward in the South China Sea. After releasing Nat, Mireille recurved under increasing southwesterly mid-tropospheric winds, and accelerated northeastward past Okinawa. Extratropical transition occurred in the Sea of Japan and the intense baroclinic storm continued northeastward, first passing over the extreme northern section of Honshu and then moving over southern Hokkaido.

The tropical cyclone initially peaked at 75 kt (39 m/sec) on 16 September and remained at moderate typhoon intensity until 21 September when it commenced a second deepening episode enroute to super typhoon intensity. This second episode was associated with decreasing upper-level wind shear from Tropical Storm Luke (20W) as that system weakened and accelerated northward. After peaking at 130 kt (65 m/sec) for a day (221200Z to 230600Z), Mireille began to slowly weaken.

Mireille's size, which was determined by the diameter of its outer-most closed isobar, began to gradually increase after an intensity of 80 kt (40 m/sec) was reached, and continued through extratropical transition.

III. FORECAST PERFORMANCE

As Mireille passed the Mariana Islands, it was difficult to determine how much the thin extension of the subtropical ridge would affect the cyclone's track. The first indications of a possible west-southwestward track excursion toward Guam came from the Beta Advection Models. OTCM also locked onto a west-southwest track after the turn had started. However, both FBAM and OTCM

overemphasized the southward excursion which lasted only a day.

After the system had passed the Marianas, recurvature forecasts were premature. The NOGAPS model underestimated the strength and duration of the subtropical ridge, and as a result all of the dynamic objective aids indicated early recurvature. The underestimation may have been the model's response to receiving three simultaneous tropical cyclone boguses in the basin corresponding to three storms. Also, the bogus, initializing the NOGAPS model, overplayed the size of Mireille, which in turn overemphasized the storm's weakening influence on the ridge.

IV. IMPACT

As Mireille approached the Mariana Islands, the wobble of its track and subsequent adjustment of the forecast to the north and back to the west, resulted in a flurry of disaster preparedness preparations on Guam northward through Saipan. When the midget typhoon passed north of Saipan, no reports of deaths or injuries were received. However, the island did suffer 70-80% crop damage, in addition to trees being uprooted, and coral roads seriously eroded. Most damage was confined to the north end of the island. Okinawa experienced 27 hours with winds greater than 50 kt (25 m/sec) and Kadena AB recorded a peak gust of 82 kt (41 m/sec). The island also recorded a total rainfall of 10.14 inches, and as a result, was able to cancel water rationing for the remainder of the

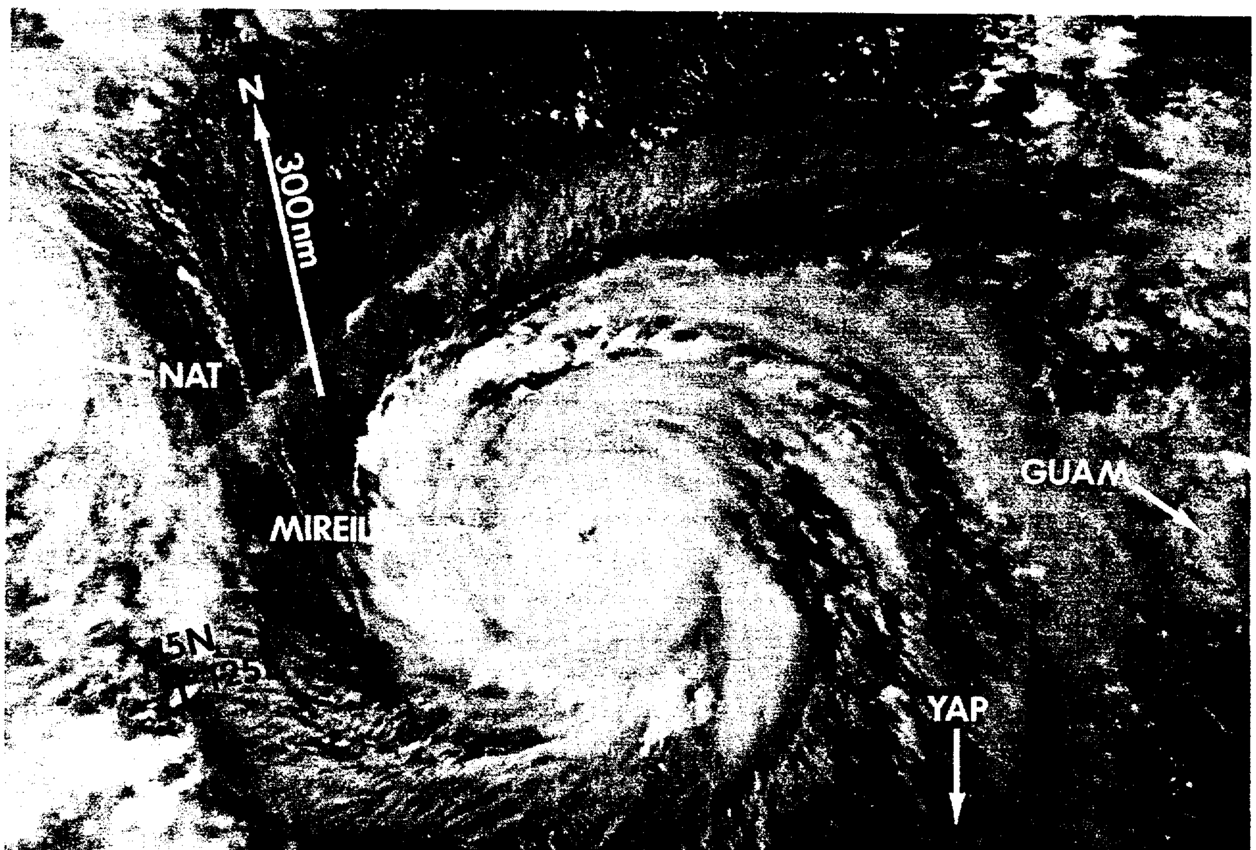


Figure 3-21-1. Moonlight view of Typhoon Mireille. A portion of Typhoon Nat's (22W) cloud shield can be see along the extreme left edge of the picture (221230Z September DMSP visual imagery).

year. Press reports from Japan indicated that 52 deaths were associated with the typhoon, including all ten crew members of a South Korean freighter that capsized while in port at Hakata on the island of Kyushu. Press reports also indicated 777 injuries, the flooding of approximately 10,000 homes, and power outages affecting nearly 6 million homes. Japanese crop damage was estimated at US$3 billion, with the apple crop being particularly hard hit. Nagasaki (WMO 47855) reported winds of 72 kt (37 m/sec) gusting to 118 kt (61 m/sec). On northern Honshu, Misawa AB recorded the most destructive winds since the U.S. started record-keeping for the base in 1946. For more than 5 hours the winds were 50 kt (25 m/sec) or greater and included a peak gust to 82 kt (41 m/sec). The previous all-time record for the base was 70 kt (35 m/sec) in March of 1987. The resulting wind damage was estimated to be between $0.5 to $1.5 million dollars. Several warehouse roofs were torn off, storage sheds were reportedly knocked off their foundations, and trees were blown down. The *Pacific Stars and Stripes* reported: "Base officials credit the Joint Typhoon Warning Center in Guam with early storm forecasts that allowed them to warn the base population and get million-dollar aircraft into hardened shelters."

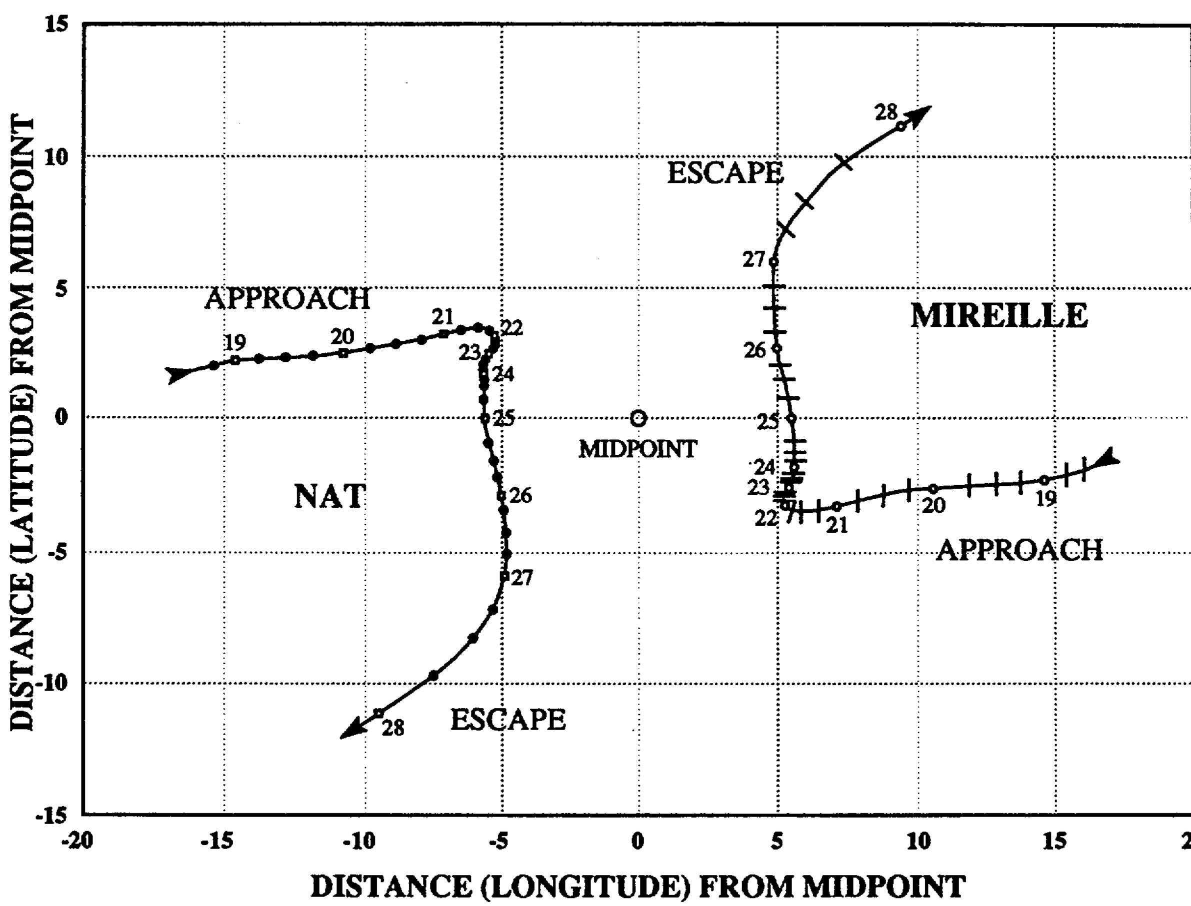
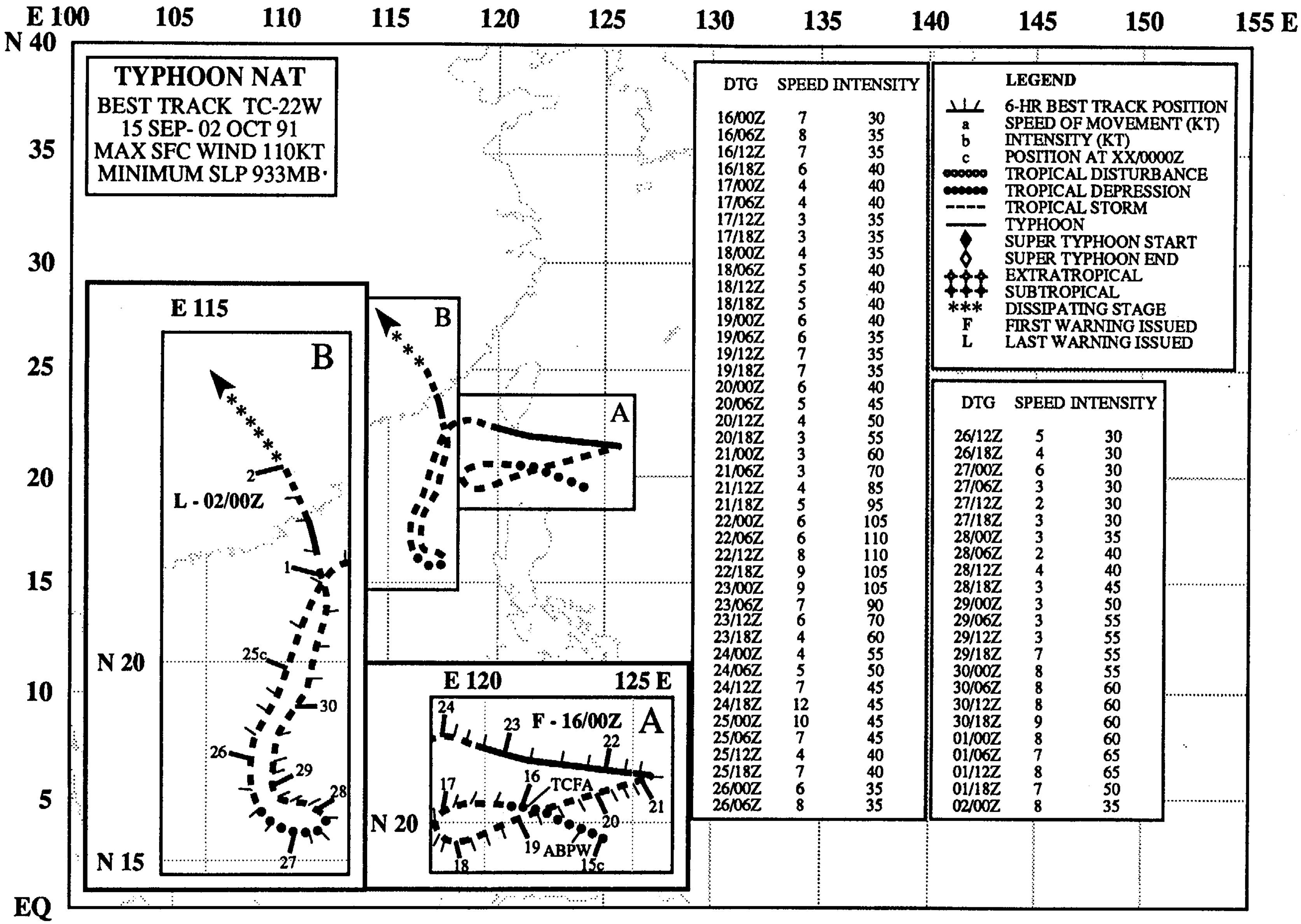


Figure 3-21-2. A plot of 6-hourly positions relative to the common midpoint shows the binary interaction between Typhoons Mireille and Nat (22W).



DTG	SPEED	INTENSITY
16/00Z	7	30
16/06Z	8	35
16/12Z	7	35
16/18Z	6	40
17/00Z	4	40
17/06Z	4	40
17/12Z	3	35
17/18Z	3	35
18/00Z	4	35
18/06Z	5	40
18/12Z	5	40
18/18Z	5	40
19/00Z	6	40
19/06Z	6	35
19/12Z	7	35
19/18Z	7	35
20/00Z	6	40
20/06Z	5	45
20/12Z	4	50
20/18Z	3	55
21/00Z	3	60
21/06Z	3	70
21/12Z	4	85
21/18Z	5	95
22/00Z	6	105
22/06Z	6	110
22/12Z	8	110
22/18Z	9	105
23/00Z	9	105
23/06Z	7	90
23/12Z	6	70
23/18Z	4	60
24/00Z	4	55
24/06Z	5	50
24/12Z	7	45
24/18Z	12	45
25/00Z	10	45
25/06Z	7	45
25/12Z	4	40
25/18Z	7	40
26/00Z	6	35
26/06Z	8	35

DTG	SPEED	INTENSITY
26/12Z	5	30
26/18Z	4	30
27/00Z	6	30
27/06Z	3	30
27/12Z	2	30
27/18Z	3	30
28/00Z	3	35
28/06Z	2	40
28/12Z	4	40
28/18Z	3	45
29/00Z	3	50
29/06Z	3	55
29/12Z	3	55
29/18Z	7	55
30/00Z	8	55
30/06Z	8	60
30/12Z	8	60
30/18Z	9	60
01/00Z	8	60
01/06Z	7	65
01/12Z	8	65
01/18Z	7	50
02/00Z	8	35

TYPHOON NAT (22W)

I. HIGHLIGHTS

Typhoon Nat's motion was highly erratic and included four major track changes, two intensification episodes, and two landfalls in 17 days. It persisted longer than any other tropical cyclone that formed in the western North Pacific during 1991, requiring a total of 61 warnings which was only 18 warnings shy of the record set by Typhoon Rita (1972). Its track and behavior was reminiscent of Typhoon Wayne (1986).

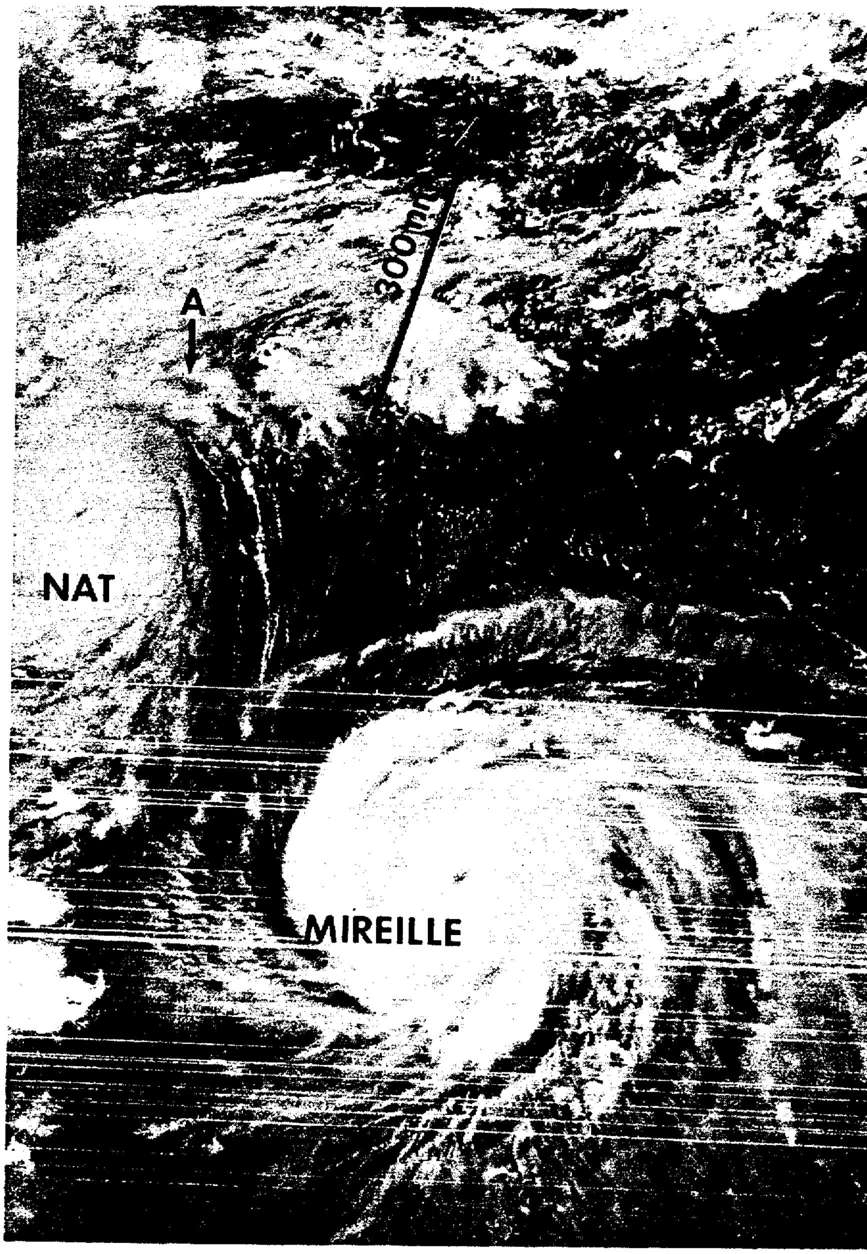


Figure 3-22-1. Moonlight imagery reveals the eyes of Typhoons Nat and Mireille (21W). Lightning flashes can be seen east of Taiwan near point A (221059Z September DMSP visual imagery).

II. TRACK AND INTENSITY

Nat's convection developed in the monsoon trough just east of the Luzon Strait and was first mentioned on the 150600Z Significant Tropical Weather Advisory. At 152300Z, improved cloud organization prompted a Tropical Cyclone Formation Alert. The alert was followed only an hour later by the first warning based on a 27 kt (14 m/sec) synoptic report and an estimated minimum sea-level pressure of 1003 mb. Nat initially intensified very slowly due to its proximity to land and to strong upper-level winds outflowing from Tropical Storm Luke (20W) which was located to the east. The influence of these two factors lessened after a surge in the southwest monsoon carried Nat to the east through the Luzon Strait, and Luke recurved. From 21 through 22 September, Nat underwent rapid deepening to almost super typhoon intensity. After Luke's departure, the ridge re-established itself and Nat (Figure 3-22-1 and 3-22-2) reversed direction to enter the Luzon Strait again. Nat made landfall (Figure 3-22-3) on the southern tip of Taiwan and rapidly weakened. Contributing factors to

the weakening were the proximity of the high mountains of Taiwan and the approach of Typhoon Mireille (21W) from the southeast with its outflow causing increased upper-level wind shear. During the binary interaction with Mireille (See Figure 3-21-2 in Mireille's write-up), Nat was downgraded to a tropical depression before the larger system, Mireille, escaped northeastward. Nat reintensified to typhoon intensity before making landfall, then dissipated over the rugged terrain of southeastern China. The final warning was issued at 020600Z.

III. FORECAST PERFORMANCE

Because the passage of two tropical cyclones to the east eroded the subtropical ridge, the steering flow in which Nat was embedded was weak. Track forecasting proved to be a real challenge, but forecast errors were respectable considering the erratic nature of the tropical cyclone. From the suite of objective aids, FBAM and CSUM seemed to provide the best overall performance. They both simulated the loop to the south caused by the surge into Tropical Storm Luke (20W); however, they were less successful in forecasting the binary interaction with Super Typhoon Mireille (21W). OTCM and NOGAPS had a very difficult time with this system. As an example, Figure 3-22-4 shows the forecast guidance for the 230000Z warning while Nat was over southern Taiwan.

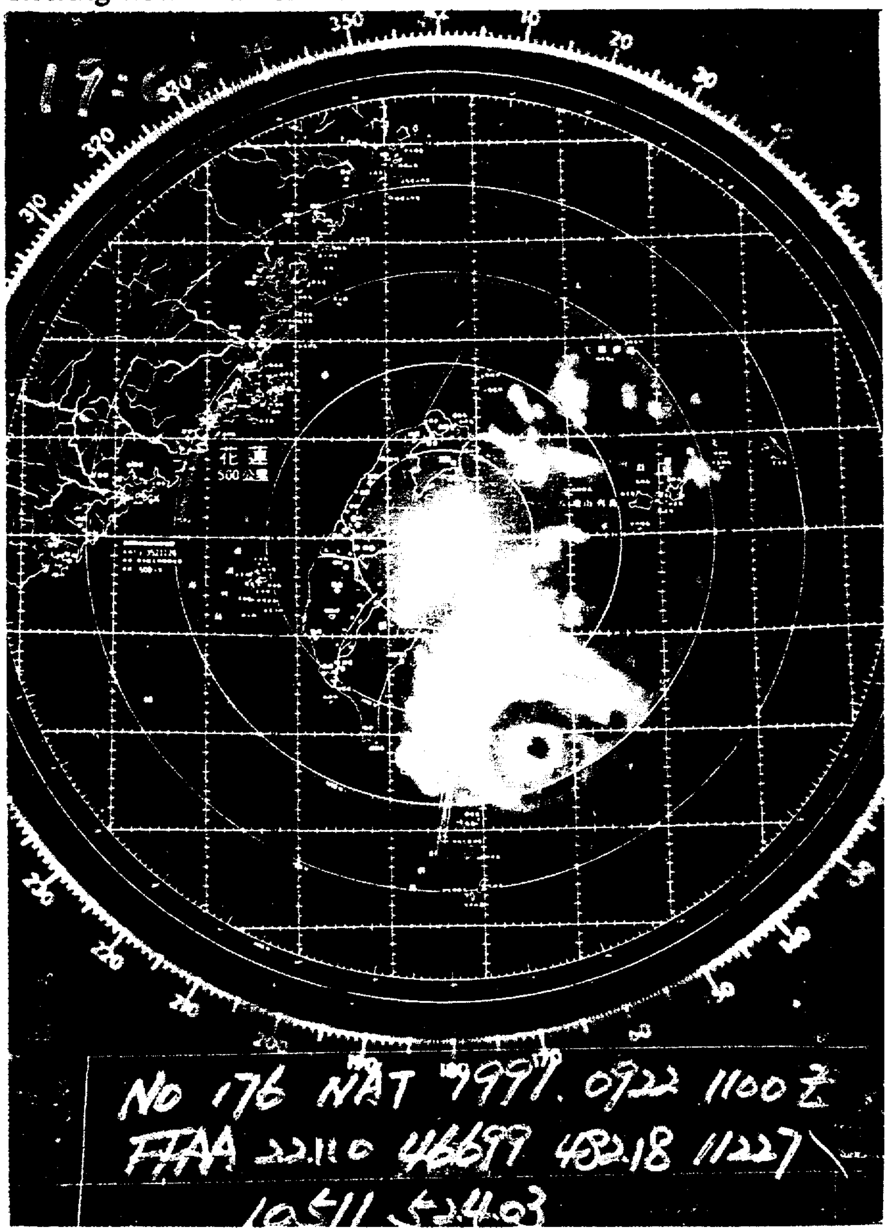


Figure 3-22-2. The radar at Haulien (WMO 46699), Taiwan paints Nat's concentric rainbands (221300Z September photo courtesy of the Central Weather Bureau, Taipei, Taiwan).

IV. IMPACT

Even though Nat was small in size and no reports were received, the typhoon's crossing of extreme southern Taiwan and, later, the southern coast of China must have disrupted communications and transportation and caused some localized damage.

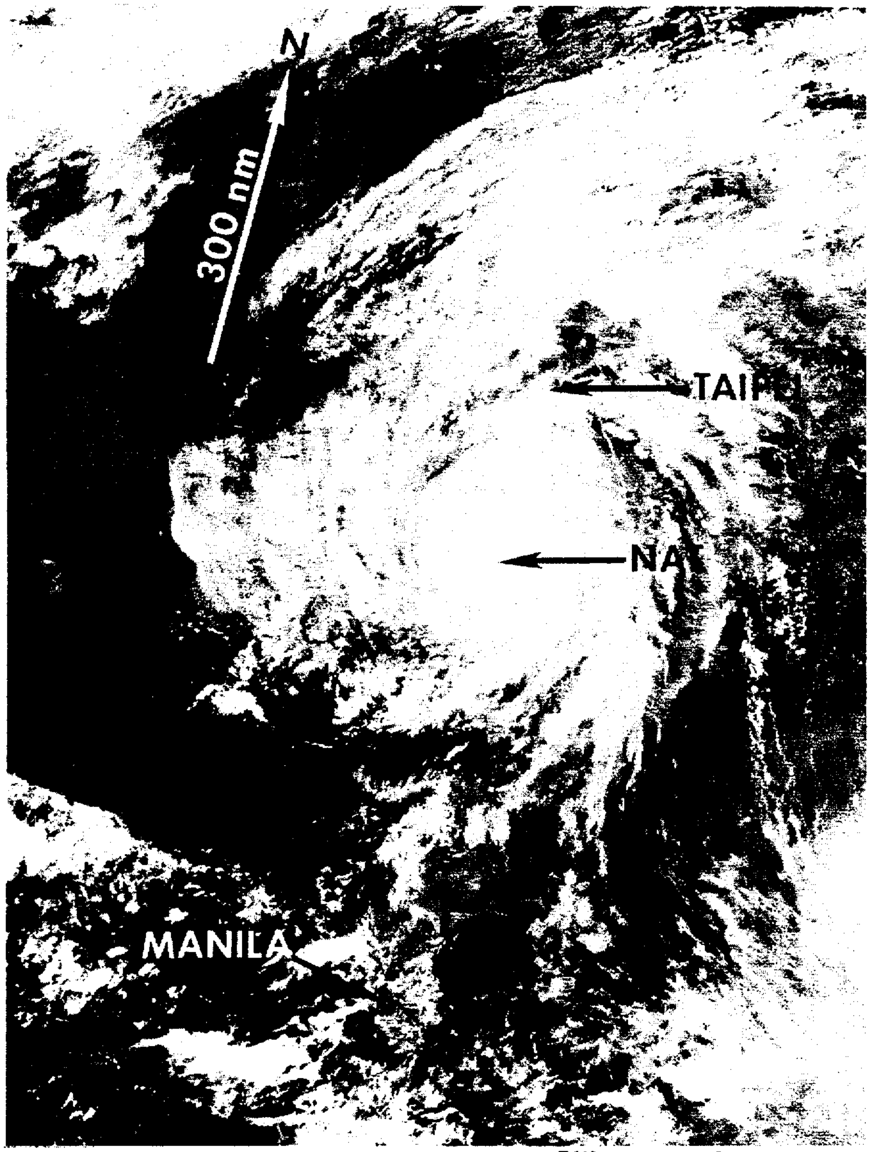


Figure 3-22-3. Nat crosses southern Taiwan (230110Z September DMSP visual imagery).

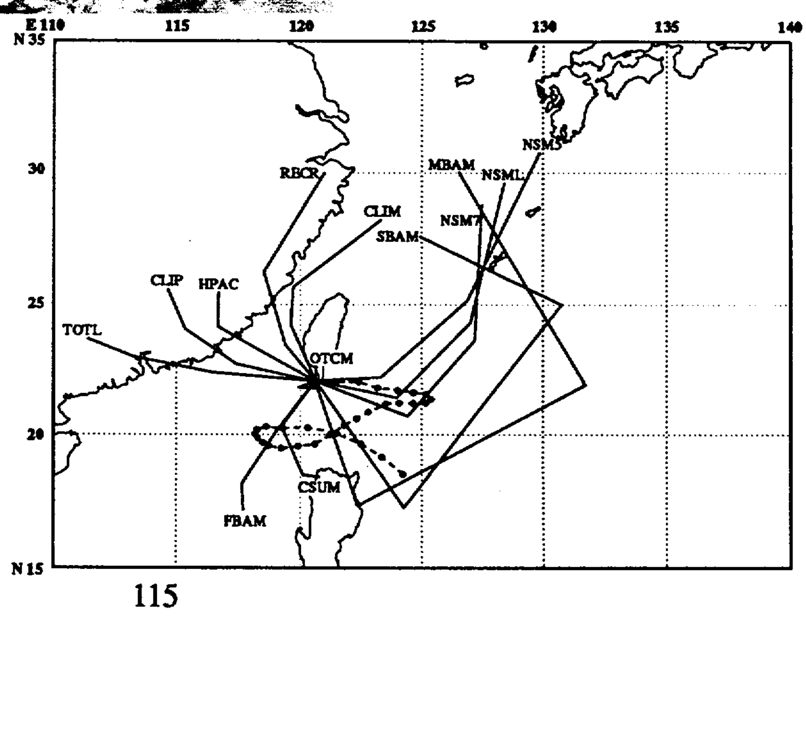
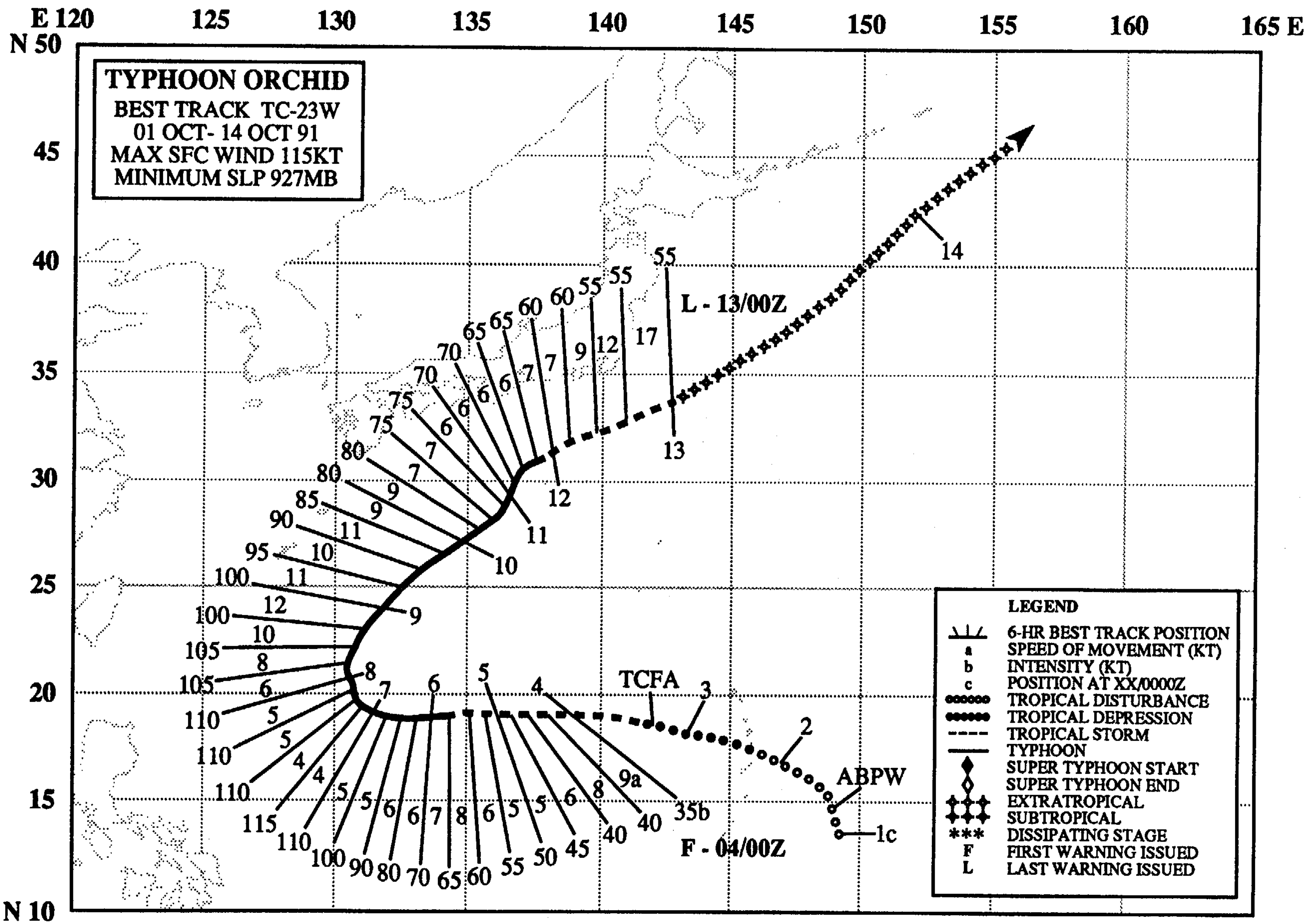


Figure 3-22-4. Forecast guidance supporting the 230000Z September warning for Typhoon Nat.


TYPHOON ORCHID
BEST TRACK TC-23W
01 OCT- 14 OCT 91
MAX SFC WIND 115KT
MINIMUM SLP 927MB
L - 13/00Z
F - 04/00Z
TCFA
ABPW
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TYPHOON ORCHID (23W)

I. HIGHLIGHTS

Typhoon Orchid (23W) was the first tropical cyclone to develop during the month of October. Orchid's formation coincided with Typhoon Pat's (24W) and, as they matured, they interacted, causing Orchid to slow to 6 kt (11 km/hr) about 200 nm (370 km) off the coast of Japan. This brought prolonged rains and widespread flooding to Tokyo and surrounding cities.

II. TRACK ANDINTENSITY

Orchid formed northwest of Guam in a broad monsoon trough that extended from the South China Sea eastward through the Caroline Islands and was included as a suspect area on the 010600Z October Significant Tropical Weather Advisory. A mid-latitude trough weakened the mid-tropospheric subtropical ridge to allow the tropical disturbance to slowly gain latitude. When low-level convergence created by a surge in the monsoon westerlies enhanced convection, forecasters issued a Tropical Cyclone Formation Alert at 030800Z. The first warning followed on Tropical Depression 23W at 040000Z. (Post analysis of satellite derived current intensity estimates indicated tropical storm intensity most probably had been reached 12 hours before the first warning through normal, rather than rapid deepening.) Orchid tracked due westward south of the re-established subtropical ridge and developed into a typhoon. Orchid's intensity peaked at 120 kt (62 m/sec) just before recurvature, as increased low-level convergence in the southern quadrant enhanced convection, and dual outflow channels aloft were present. Recurvature occurred near 130°E as the mid-tropospheric subtropical ridge receded eastward, allowing Orchid to move north and recurve. Typhoon Orchid slowly accelerated after recurvature, but on 10 October it slowed down south of Japan as interaction started with Typhoon Pat (24W) (Figure 3-23-1). Over a 40-hour period from approximately 100600Z - 120000Z, Orchid "stair-stepped" to the north then back to the northeast apparently due to some binary interaction with Typhoon Pat. As Pat recurved to the east of Orchid and accelerated, Orchid started speeding up, following Pat into the westerlies, and slowly weakening. The final warning was issued at 130000Z as Orchid transitioned into an extratropical low pressure system.

III. FORECAST PERFORMANCE

During recurvature, Orchid was expected to make a more gradual, broader turn around the ridge because the steering flow was weak, as evidenced by the slow speed of motion from 4 to 6 kt (7 to 11 km/hr) on 6 to 7 October. Initially, the typhoon was forecast to pass near Okinawa, west of the guidance provided by most of the dynamic aids (Figure 3-23-2). After recurvature, cross-track forecasts were excellent, although the along-track speed errors were large because the expected forecast acceleration did not take place until Pat moved north of Orchid.

VI. IMPACT

Typhoon Orchid spent much of its life over the open ocean, away from land. However, its slow movement south of Japan caused prolonged rains there, and created huge ocean swells, which combined with those from Pat to produce high waves and hazardous surf as far away as Guam on October 12, where the surf claimed 2 lives. On 14 October, landslides, floods, heavy winds, and torrential rains were reported in Tokyo and the surrounding cities. One person died after being swept away by a swollen river, 14 people were injured and wind gusts to 50 kt (26 m/sec) were recorded in

and around Tokyo. Orchid interrupted transportation across the island, produced 96 landslides, flooded over 675 homes, and caused extensive road damage in Japan.

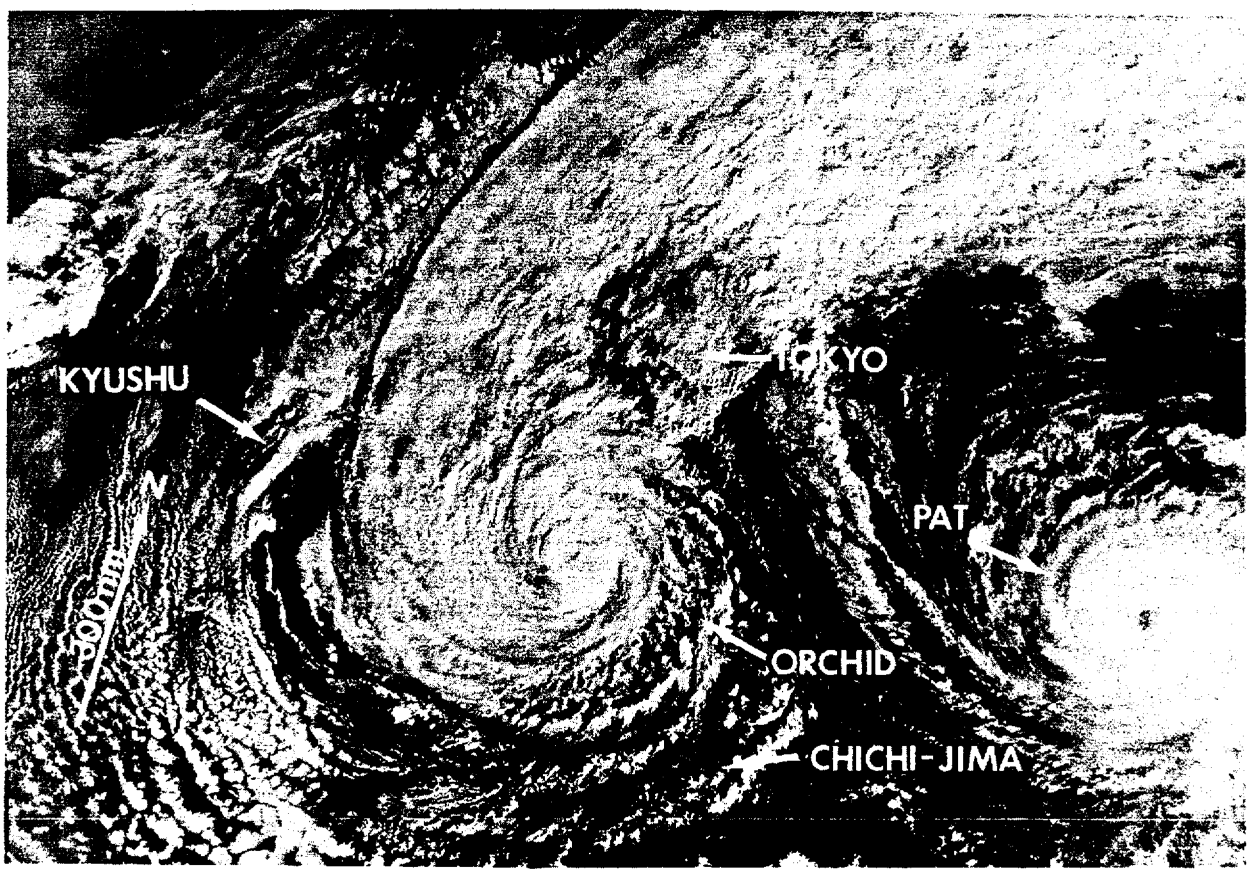


Figure 3-23-1. Typhoon Orchid slowly weakens as it parallels the south coast of Honshu, Japan (112322Z October DMSP visual imagery).

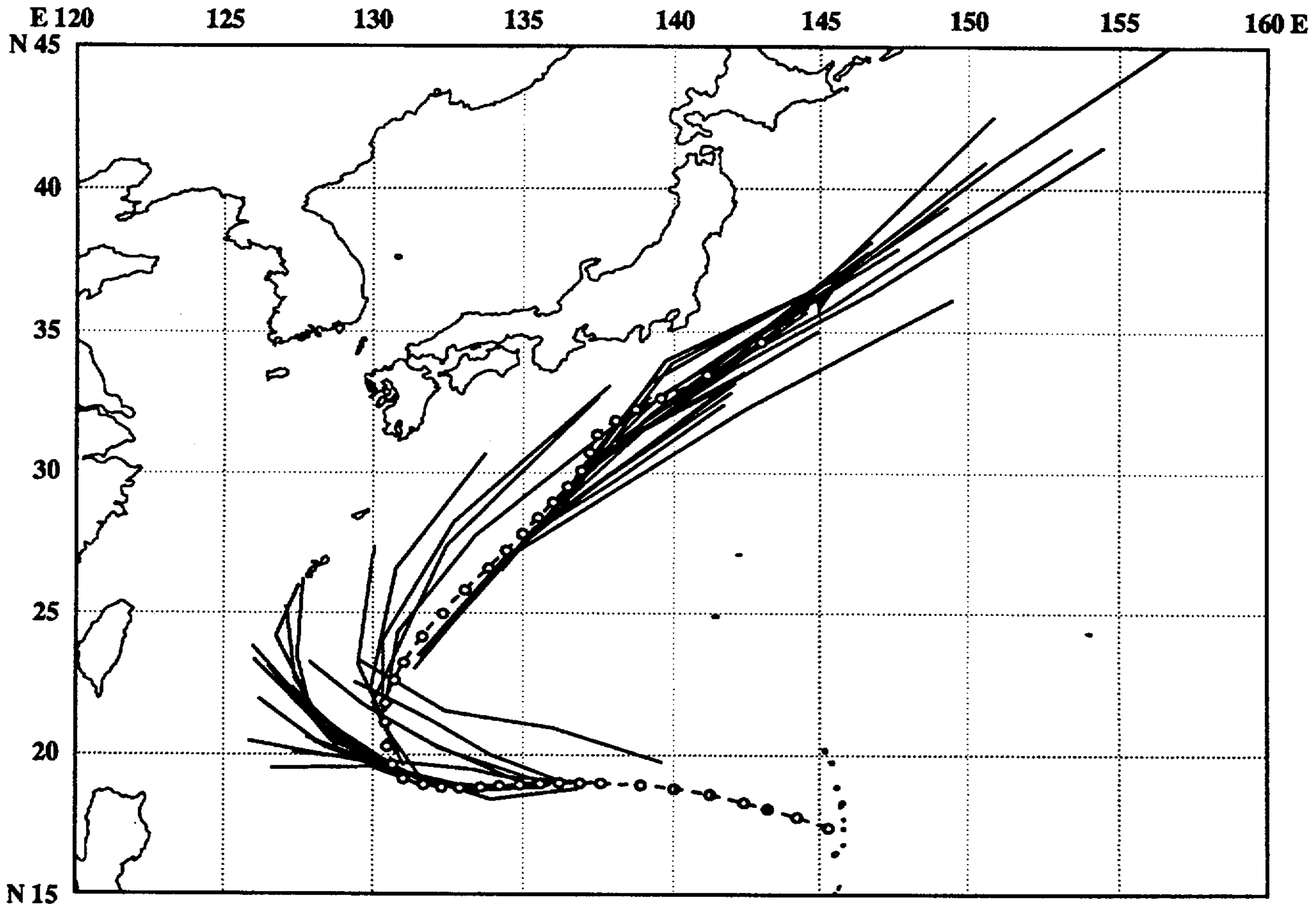
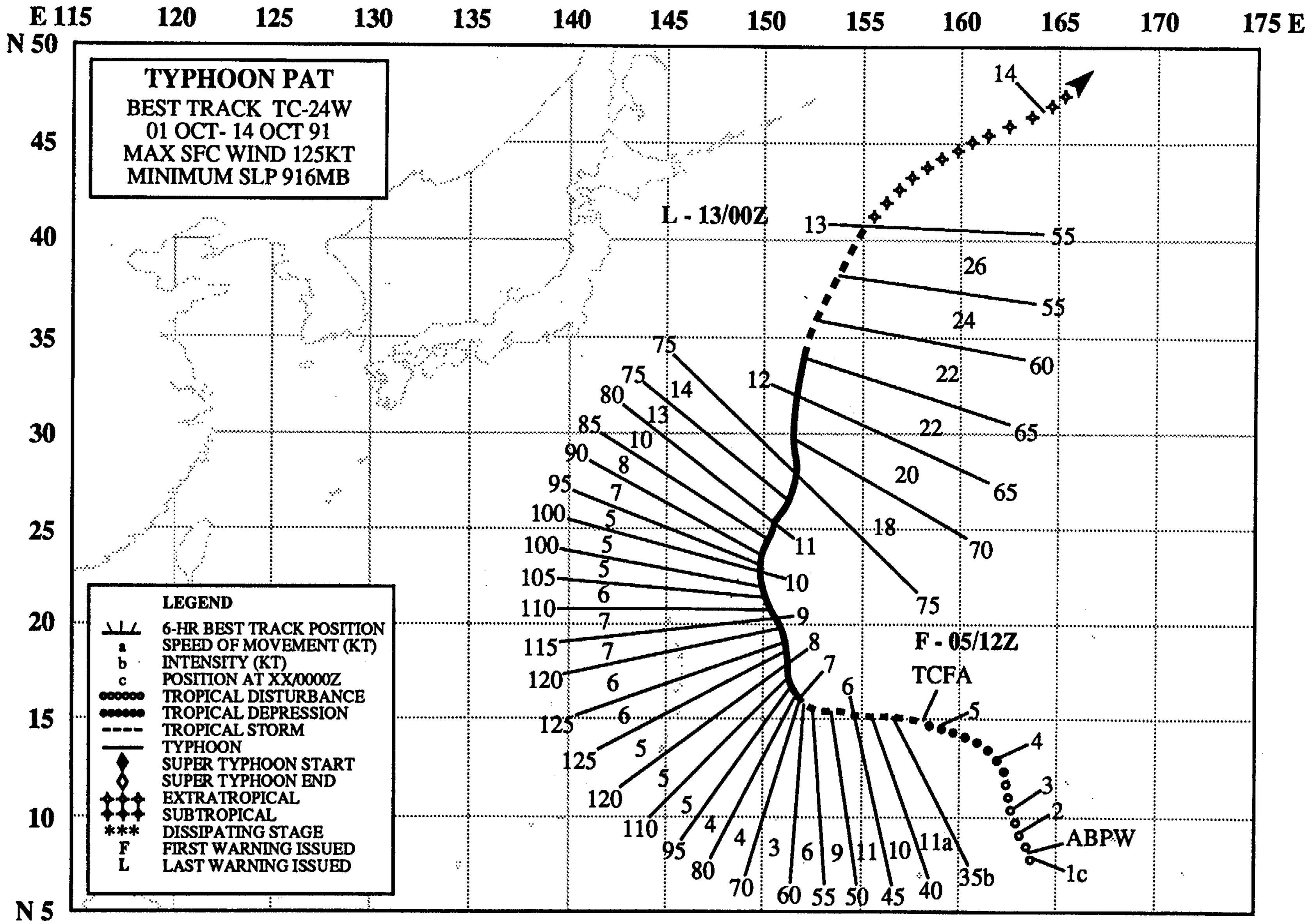


Figure 3-23-2. JTWC forecasts when compared to the final best track show that Orchid turned north sooner than expected.


TYPHOON PAT
BEST TRACK TC-24W
01 OCT- 14 OCT 91
MAX SFC WIND 125KT
MINIMUM SLP 916MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L - 13/00Z
F - 05/12Z
TCFA
ABPW
E 115
120
125
130
135
140
145
150
155
160
165
170
175 E
N 50
45
40
35
30
25
20
15
10
N 5

TYPHOON PAT (24W)

I. HIGHLIGHTS

Typhoon Pat developed at the same time in early October as Typhoon Orchid (23W). Its rapid intensification phase was correctly predicted by a recently developed pixel-counting forecast scheme. Although Pat initially trailed Orchid as the two tropical cyclones matured, it accelerated and was the first to become extratropical.

II. TRACK AND INTENSITY

After Typhoon Nat (22W) dissipated over southeastern China and the monsoon trough re-established itself eastward into the Caroline and Marshall Islands, two tropical disturbances formed in this trough. These disturbances were discussed on the 010600Z October Significant Tropical Weather Advisory. Pat developed from the disturbance in the western Marshall Islands, and the other disturbance to the west became Typhoon Orchid (23W). Initially, tropical cyclone development was hampered by vertical wind shear. On 4 October, vertical shear decreased and the depression began to slowly intensify. Based on a steady increase in convective organization, a Tropical Cyclone Formation Alert was issued at 050630Z, followed by the first warning at 051200Z. Pat intensified at a normal rate of 20 kt (10 m/sec) per day until 061800Z, when it began to rapidly intensify (Figure 3-24-1). At about the same time, the ridge weakened to the north, allowing the typhoon's track to change from west-northwestward to north-northwestward for the next 72 hours. Typhoon Pat attained a maximum

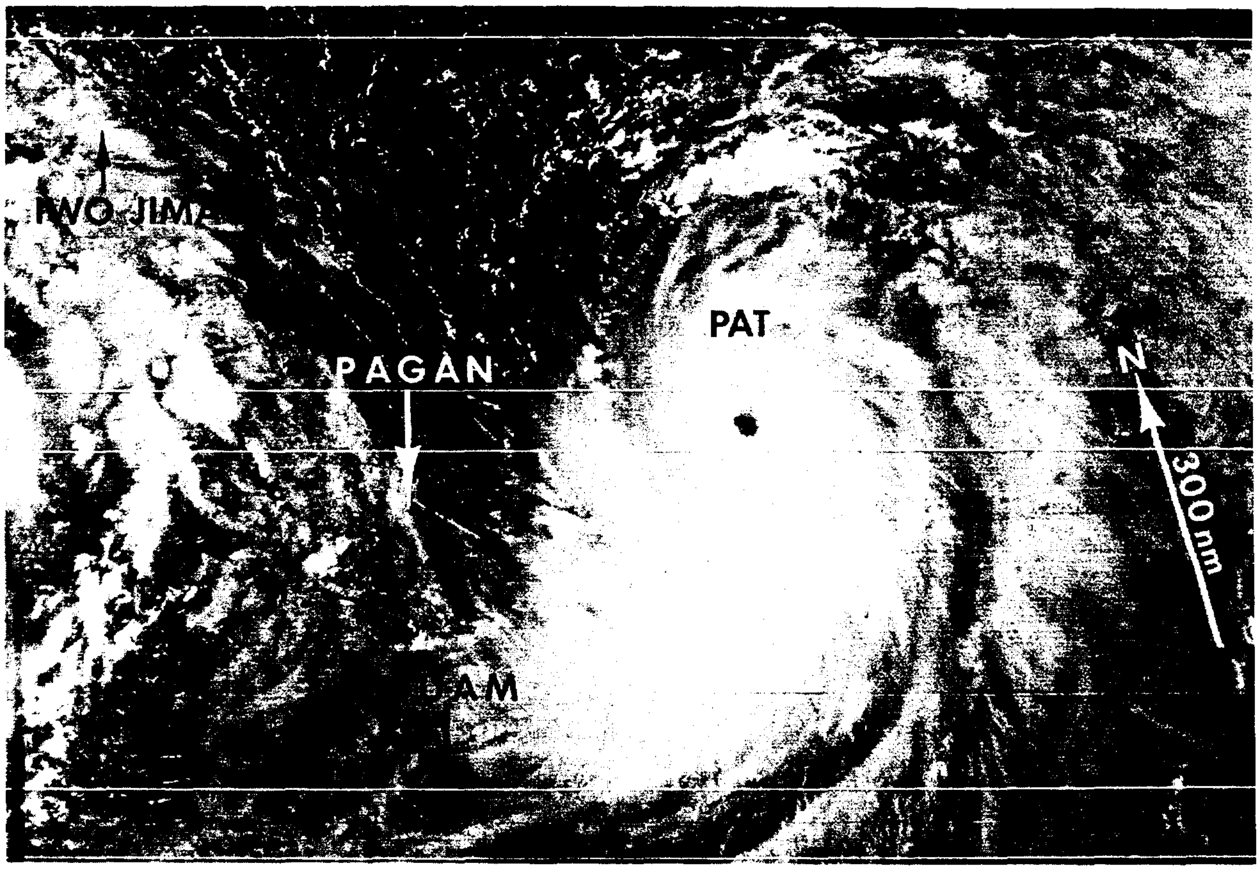


Figure 3-24-1. Typhoon Pat nears it maximum intensity (072237Z October DMSP visual satellite imagery).

intensity of 125 kt (64 m/sec) on 8 October, approximately 320 nm (590 km) east of Pagan Island in the northern Mariana Islands. As the system began to weaken, the subtropical high located to the east maintained its strength and position. As a result, Pat began to approach Orchid, which was recurving south of Japan. By 100000Z, the two systems had closed to within 1000 nm (1850 km) of each other. Instead of undergoing binary interaction and orbiting around a common midpoint, Pat and Orchid maintained their separation and moved in tandem to the north-northeast (Figure 3-24-2). Although initially the trailing cyclone, Pat accelerated poleward first, and the slow-moving Orchid followed in its wake. Both became extratropical at 130000Z.

III. FORECAST PERFORMANCE

Interaction with Orchid was the most difficult portion of Pat's track to forecast. Initially the prognostic messages indicated that Orchid, which had recurved first and was located further north than Pat, was more likely to be the first to accelerate northeastward. However, Pat became the first to accelerate. Surprisingly, climatology was the best-performing forecast aid at 72 hours, with a forecast error of only 201 nm (370 km).

The start of Pat's rapid intensification on 7 October was successfully predicted by a new pixel-counting technique (Mundell, 1990) which compares the ratio of inner-radius convection to outer-radius convection to forecast rapid intensity change (Figure 3-24-3). Overall intensity forecasting errors were slightly higher than the average.

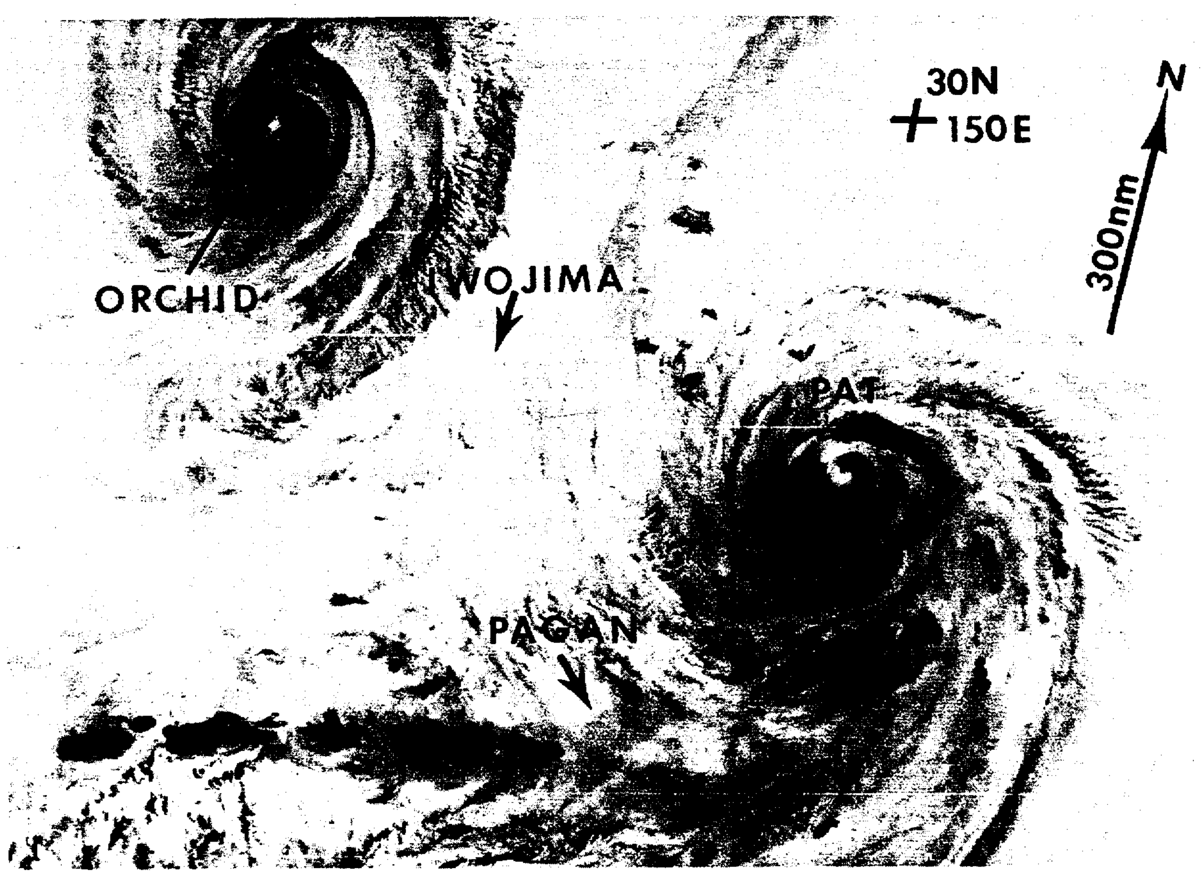


Figure 3-24-2. Typhoons Pat and Orchid (23W) are both moving north-northeastward in tandem (101011Z October DMSP infrared imagery).

IV. IMPACT

JTWC did not receive any information of direct impacts of Pat. However, indirectly, the slow movement of Pat and Orchid set up significant long period ocean swells that gave Guam some of its largest surf of the year. At least two people lost their lives on Guam due to the high surf.

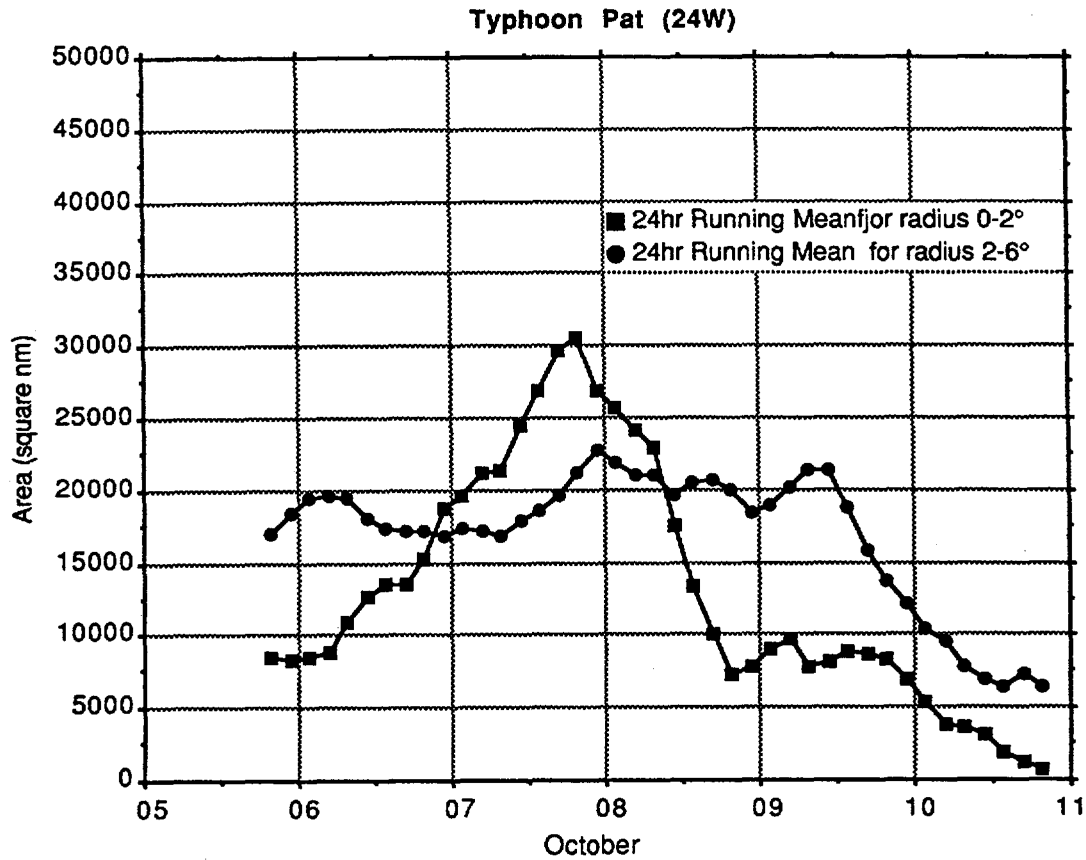
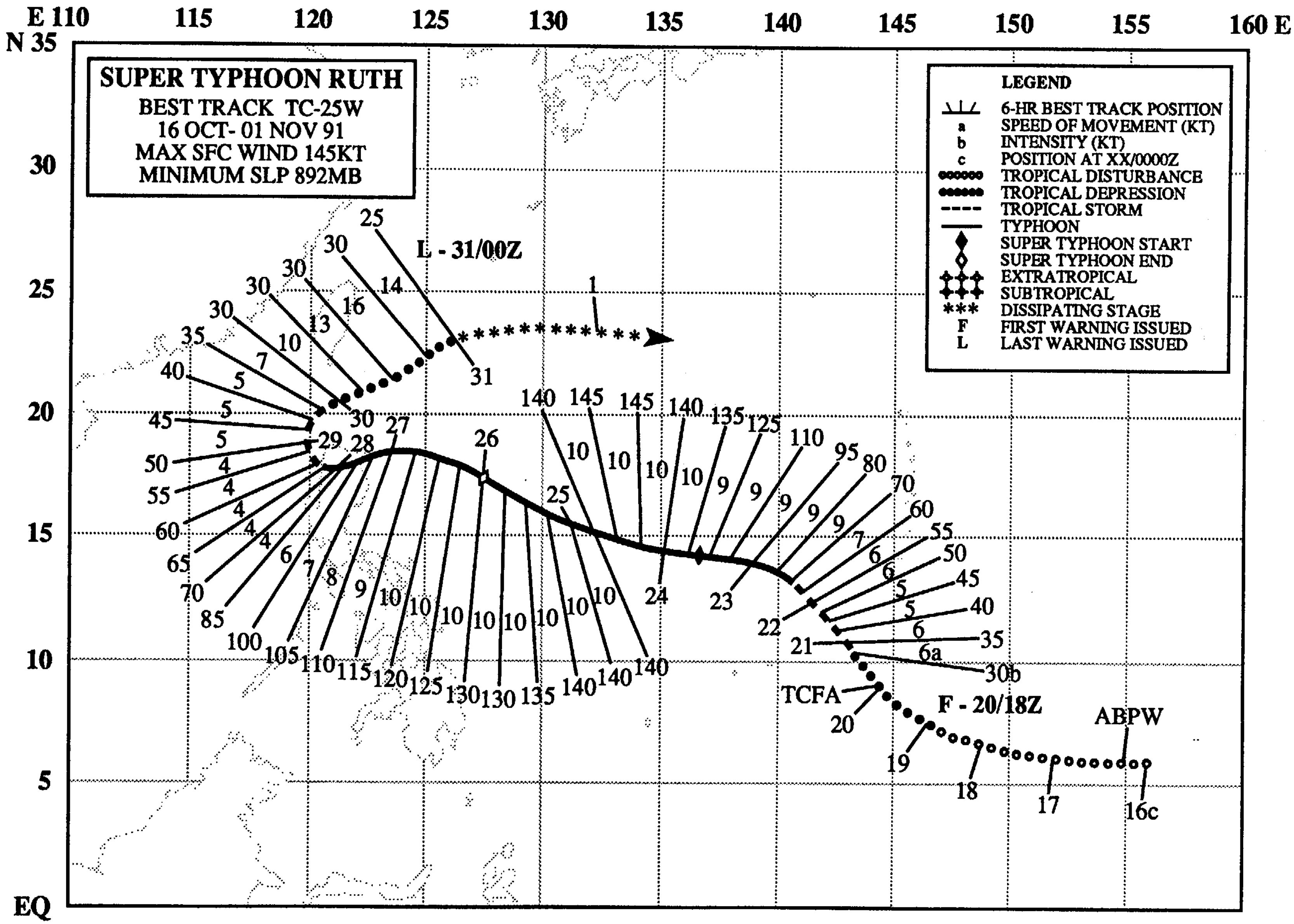


Figure 3-24-3. Time series of the relative amounts of inner convection (measured within 2° of the cloud system center) colder than -75°Celsius and outer convection (measured within 2°-6° of the center) colder than -65°Celsius. According to Mundell (1990), when the lines representing 24-hour running mean averages of both inner and outer convection cross, rapid intensification is likely to occur over the next 12 hours.


SUPER TYPHOON RUTH
BEST TRACK TC-25W
16 OCT- 01 NOV 91
MAX SFC WIND 145KT
MINIMUM SLP 892MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 110
115
120
125
130
135
140
145
150
155
160 E
N 35
30
25
20
15
10
5
EQ
L - 31/00Z
F - 20/18Z
TCFA
ABPW

SUPER TYPHOON RUTH (25W)

I. HIGHLIGHTS

Super Typhoon Ruth was the second most intense tropical cyclone of 1991. With regard to intensity, forecasters successfully used climatological analogs to anticipate Ruth's rapid deepening to super typhoon intensity in the Philippine Sea. However, in contrast, the track forecasts based on NOGAPS prediction of early recurvature had the largest forecast track errors of the year.

II. TRACK AND INTENSITY

Ruth appeared as a tropical disturbance with a closed circulation at the surface between Chuuk and Pohnpei. Observed pressure falls of 1 to 2 mb over the previous 24 hours persuaded forecasters to mention the disturbance on the 160600Z October Significant Tropical Weather Advisory as an area with fair potential for development. On 18 and 19 October, there was a steady increase in convection as the disturbance moved west-northwestward through the Caroline Islands. The increased convection prompted the issuance of a Tropical Cyclone Formation Alert at 200100Z. Based on a Dvorak intensity estimate of 25 kt (13 m/sec) and increased convective organization, the first warning on Tropical Depression 25W was issued at 201800Z.

Ruth intensified steadily as it moved northwestward between Guam and Ulithi. On 22 October, an eye formed as the tropical cyclone "stair stepped" westward. After assuming a west-northwestward track across the Philippine Sea, Ruth rapidly intensified, reaching super typhoon intensity only 30 hours after its eye first appeared on satellite imagery (Figure 3-25-1). Ruth's track and explosive intensity increase were

Figure 3-25-1. Ruth at super typhoon intensity in the Philippine Sea (231816Z October NOAA infrared imagery).

consistent with climatological guidance. Nine analog tropical cyclones from a 20-year data set (Table 3-25-1) were found. Six of the nine had rapidly intensified to super typhoon intensity, and the majority had maintained a west-northwest track across the Philippine Sea. Ruth's intensity peaked at 145 kt (75 m/sec) at 240600Z and then slowly weakened as the typhoon approached northern Luzon. During this weakening phase, the eye expanded from a diameter of 10 nm (19 km) to 60 nm (110 km).

On 25 October, a mid-tropospheric trough moving eastward from China temporarily weakened the ridge and Ruth turned northwestward. Then the subtropical ridge re-established itself, and on 27 October Ruth tracked west-southwestward into northern Luzon. The typhoon lashed the northern coast of Luzon with winds in excess of 100 kt (51 m/sec) before weakening to tropical storm intensity over land. On 28 October another migrating mid-tropospheric trough, deeper than the previous one, picked up Tropical Storm Ruth and caused it to recurve south of Taiwan. The tropical cyclone continued to weaken as it moved northeastward, and JTWC issued the final warning on the system at 310000Z.

III. FORECAST PERFORMANCE

The track forecasts were excellent until 250000Z, when the forecast scenario changed from straight-running, west-northwestward to recurvature (Figure 3-25-2). Low track and intensity errors for the first 17 warnings had been a reflection of the climatological analogs.

Starting with the 231200Z dynamic model run, the NOGAPS prognoses began to deviate from the climatological track guidance by predicting early recurvature and then acceleration (Figure 3-25-3). Based on NOGAPS' previous successes, the forecast scenario switched from straight runner to recurver for the 250000Z through 261200Z warnings. When Ruth continued to move west-northwestward and the upper air analyses indicated 500 mb heights were rising over Taiwan, it became apparent that the NOGAPS guidance was erroneous. The result was six 72-hour forecast with errors in excess of 500 nm (925 km), including two over 900 nm (1665 km) - the largest busts of the year.

IV. IMPACT

Super Typhoon Ruth was the most intense tropical cyclone of 1991 to strike Luzon. On northern Luzon 12 people were killed as Ruth triggered numerous landslides and flooding leaving at least 76,000 residents homeless. Fortunately, very little rain fell near Mount Pinatubo where it would have caused mudflows, lahars, and additional devastation. At sea, 18 lost their lives when the freighter **Tung Lung** sank west of Taiwan. Another 18 crewman were rescued from heavy seas after the freighter

Table 3-25-1. Listing of nine analog tropical cyclones from 1970 to 1990 which had the greatest similarity to Ruth's track and intensity, along with their 24-, 48-, and 72-hour track and intensity change.

TC	DTG	INITIAL PSN (INT)	24 HOUR MOVMT (INT)	48 HOUR MOVMT (INT)	72 HOUR MOVMT (INT)
Ruth	91102118	12.0N 142.0E (50)	NW at 7 kt (80)	W at 9 kt (135)	WNW at 10 kt (140)
Irma	71111106	11.2N 139.4E (60)	NW at 15 kt (95)	NW at 15 kt (150)	NW at 9 kt (120)
Patsy	73100706	13.4N 140.8E (45)	WNW at 7 kt (65)	WNW at 9 kt (95)	WNW at 10 kt (140)
Louise	76103112	11.0N 142.1E (50)	W at 12 kt (75)	WNW at 14 kt (135)	WNW at 13 kt (140)
Kim	77110800	13.2N 147.4E (50)	W at 15 kt (95)	W at 14 kt (120)	W at 10 kt (120)
Tip	79100906	12.7N 145.8E (55)	W at 10 kt (85)	WNW at 6 kt (140)	NW at 7 kt (165)
Betty	80103006	11.7N 149.1E (55)	WNW at 20 kt (80)	W at 16 kt (95)	W at 11 kt (100)
Marge	83110118	13.6N 141.1E (45)	WNW at 8 kt (75)	WNW at 8 kt (130)	WNW at 7 kt (140)
Dot	85101400	11.6N 142.4E (50)	W at 12 kt (75)	WNW at 10 kt (140)	W at 13 kt (150)

Southern Cross sank northeast of Taiwan.

The large track forecast errors resulted in a short notice for DOD assets on northern Luzon to prepare for the typhoon and unnecessary typhoon preparations from Okinawa to Japan.

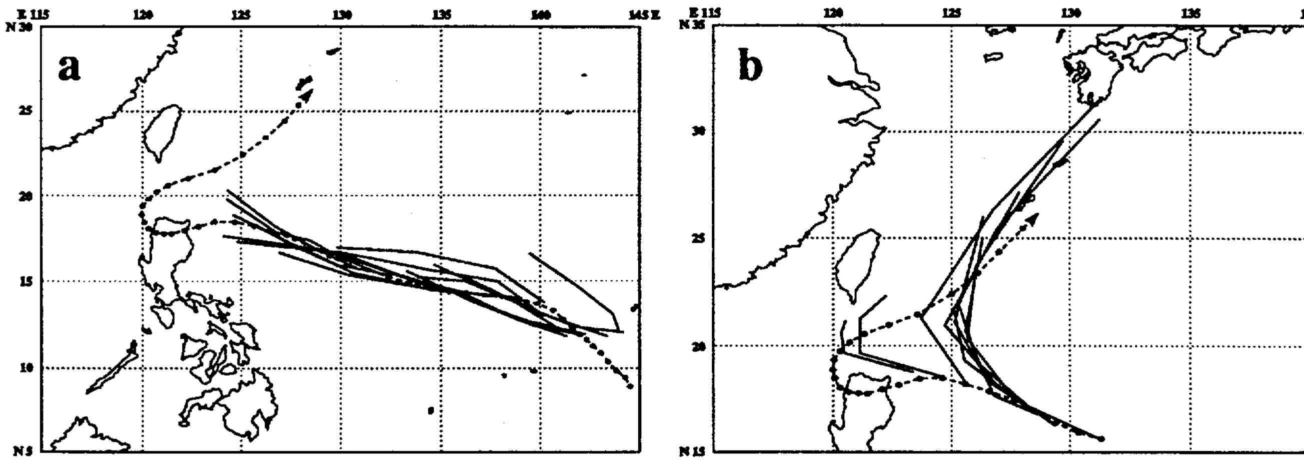


Figure 3-25-2. (a) Comparison of the first 17 warnings (201800Z to 241800Z) to the official JTWC best track and, (b) comparison of the next nine warnings (250000Z to 270000Z) to the official JTWC best track.

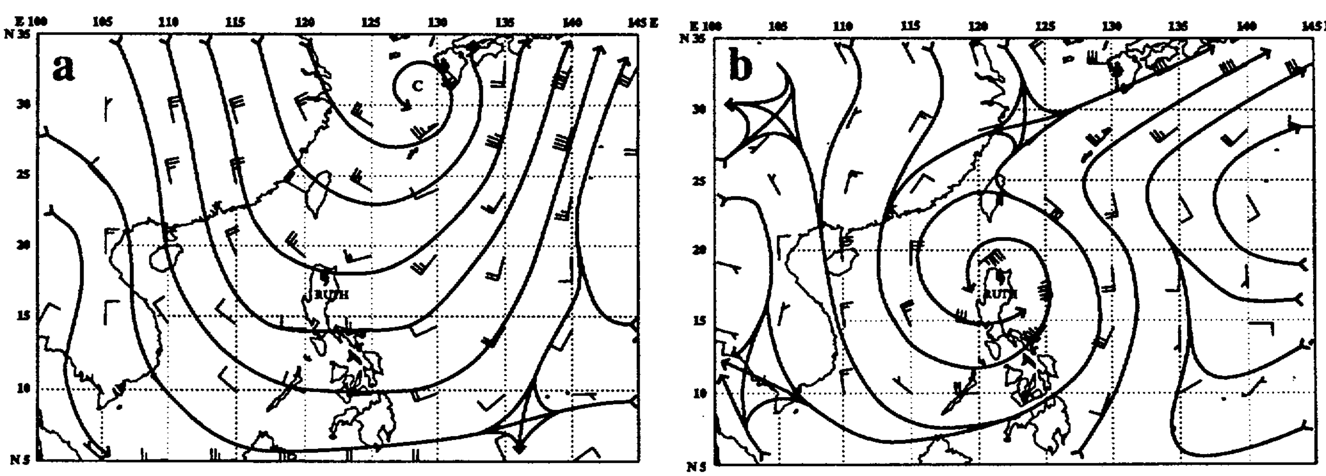
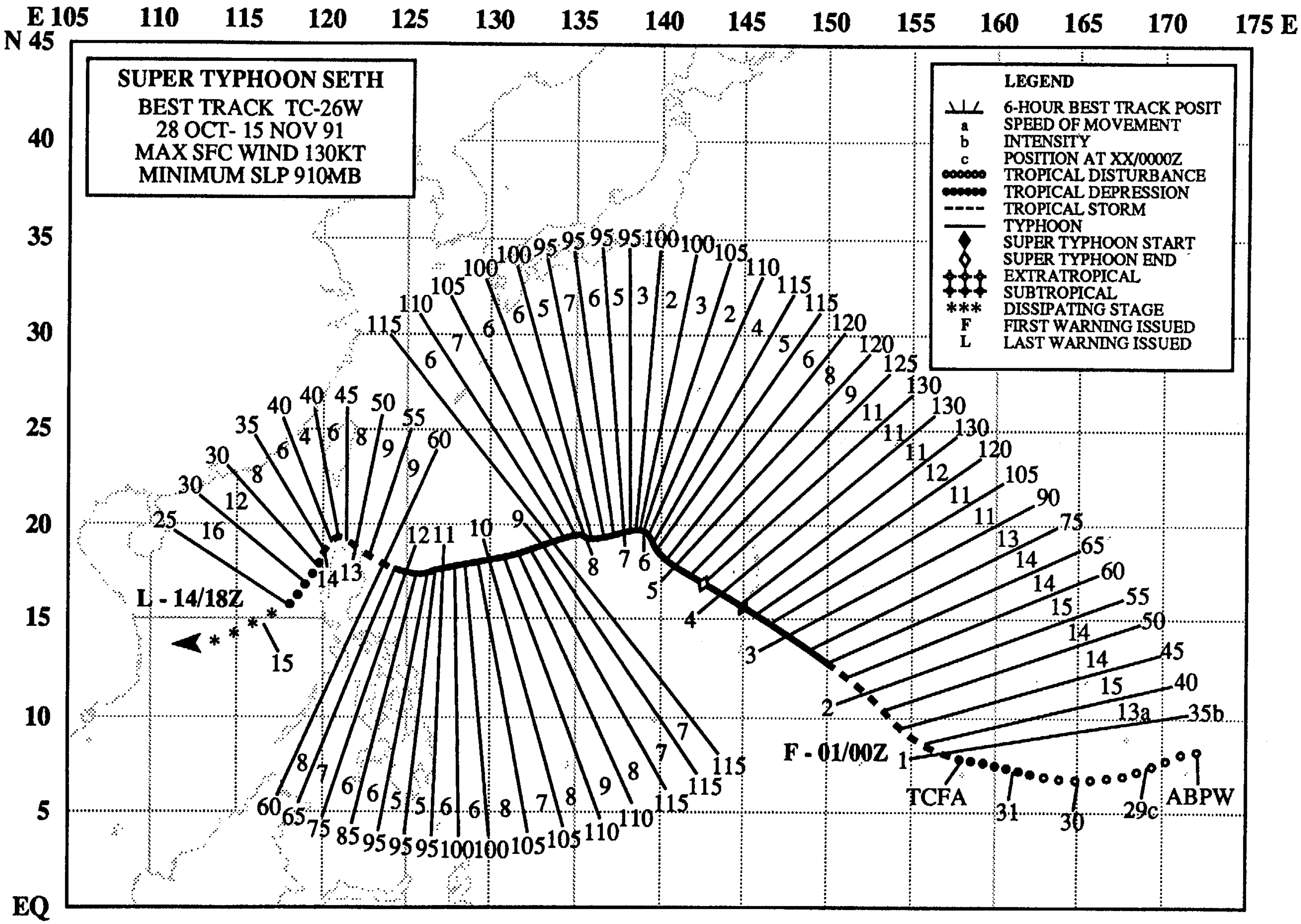


Figure 3-25-3. (a) Comparison of the NOGAPS 250000Z 700-mb 72-hour forecast, valid at 280000Z, to the (b) verifying NOGAPS analysis at 280000Z.


SUPER TYPHOON SETH
BEST TRACK TC-26W
28 OCT- 15 NOV 91
MAX SFC WIND 130KT
MINIMUM SLP 910MB
LEGEND
6-HOUR BEST TRACK POSIT
a SPEED OF MOVEMENT
b INTENSITY
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 105
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165
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175 E
N 45
40
35
30
25
20
15
10
5
EQ
L - 14/18Z
F - 01/00Z
TCFA
ABPW
13a
35b
29c
31
30

SUPER TYPHOON SETH (26W)

I. HIGHLIGHTS

Super Typhoon Seth was the first of six tropical cyclones to reach at least typhoon intensity in the month of November. This was the most active November in the western North Pacific since 1964. Forecasts for Seth's generally westward track were complicated by the normally reliable objective guidance suggesting recurvature which did not occur.

II. TRACK AND INTENSITY

Seth originated as a weak disturbance in the southern Marshall Islands, and was mentioned on the 280600Z October Significant Tropical Weather Advisory. Synoptic and satellite data for the next several days indicated slow development. A Tropical Cyclone Formation Alert was issued at 311730Z October based on a significant increase in the amount and organization of convection over the preceding 12 hours. More convection and the detection of a circulation defined by low-level cloud lines on visual satellite imagery prompted the first warning at 010000Z November.

The tropical cyclone continued tracking west-northwestward and intensified rapidly. With a faster than normal rate of intensification supported by dual outflow channels aloft, the system quickly peaked, reaching a maximum intensity of 130 kt (67 m/sec) at 031800Z (Figure 3-26-1). On 4 November Seth started to slow as it approached the axis of the subtropical ridge and the anticipated point of recurvature. However, the ridge strengthened as the super typhoon weakened, and Seth became almost stationary for 24 hours before resuming a slow, west-southwestward track on 6 November.

For the next 5 days, Seth continued west-southwestward and briefly reintensified. During this period Seth and Tropical Storm Verne (28W), located to the east, closed to within 800 nm (1480 km) of each other. While the influence was nominal due to the large separation distance, Verne weakened the ridge to the north and contributed to the slowing of Seth. On 12 November Seth gradually turned northwestward as it approached northern Luzon. This turn appeared to be in response to a weakness in the ridge west of Taiwan. However, once again the ridge strengthened, and the tropical cyclone turned southwestward along the edge of a low-level surge from the northeast. Due to shear and land affects, Seth continued to weaken as it moved into the South China Sea and dissipated. The final warning was issued at 141800Z.

III. FORECAST PERFORMANCE

Seth's track was difficult to forecast because of the narrow subtropical ridge and the objective guidance which kept suggesting recurvature. As the track neared 140°E longitude, the Colorado State University Model (CSUM) proved to be the best performer, aided by its tendency to be slow in recurvature situations. Once Seth moved westward from the bifurcation point near 140°E, JTWC's forecast performance improved significantly (Figure 3-26-2).

IV. IMPACT

As Seth brushed by Saipan in the Northern Mariana Islands on 3 November no fatalities were reported, but significant property and crop damage occurred. Estimates of damage to public facilities alone were as high as US$2 million. Families were evacuated from low lying areas, and 9.5 inches (240 mm) of rain caused widespread flooding. Later, when Seth tracked through the Luzon Strait, no reports of property damage or injury were received.

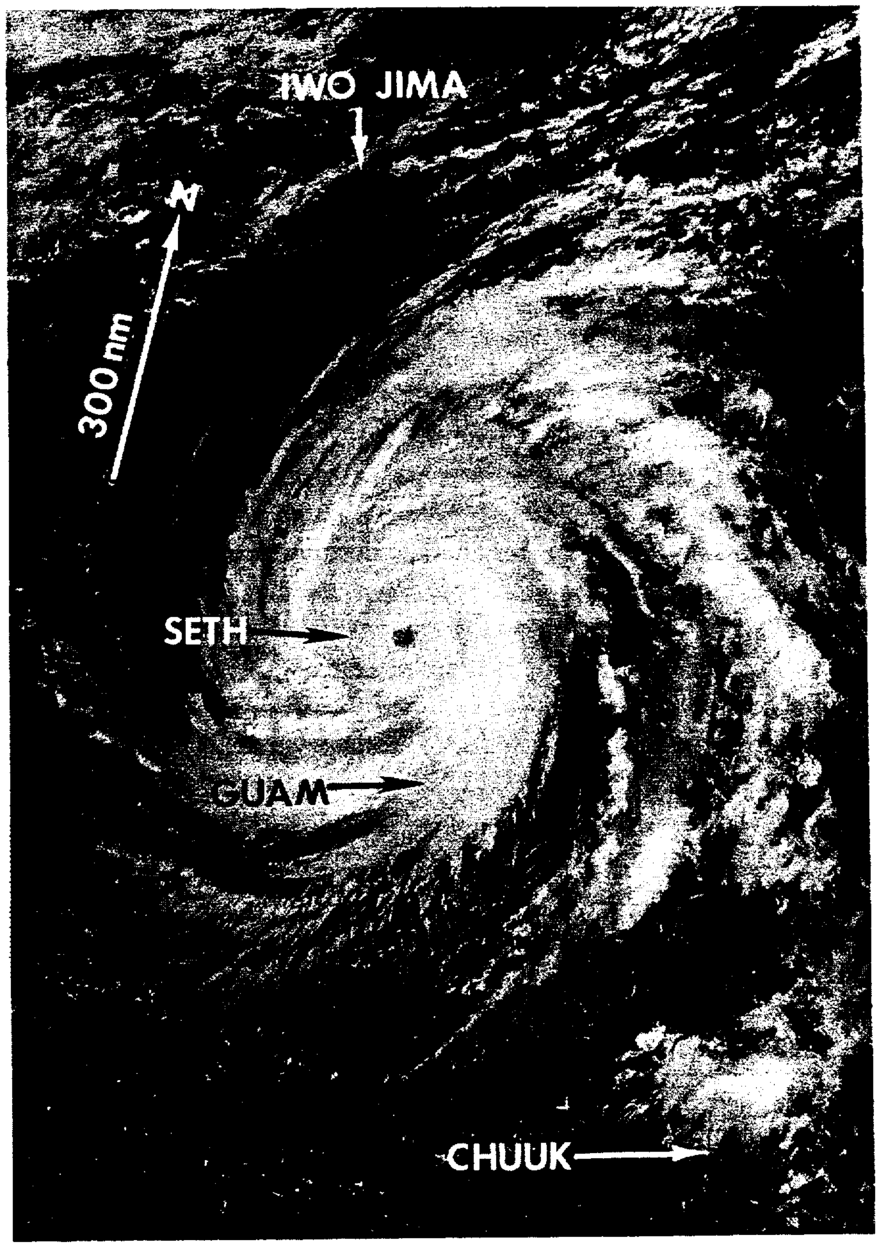


Figure 3-26-1. Satellite imagery shows Super Typhoon Seth at its peak intensity (032330Z November DMSP visual imagery).

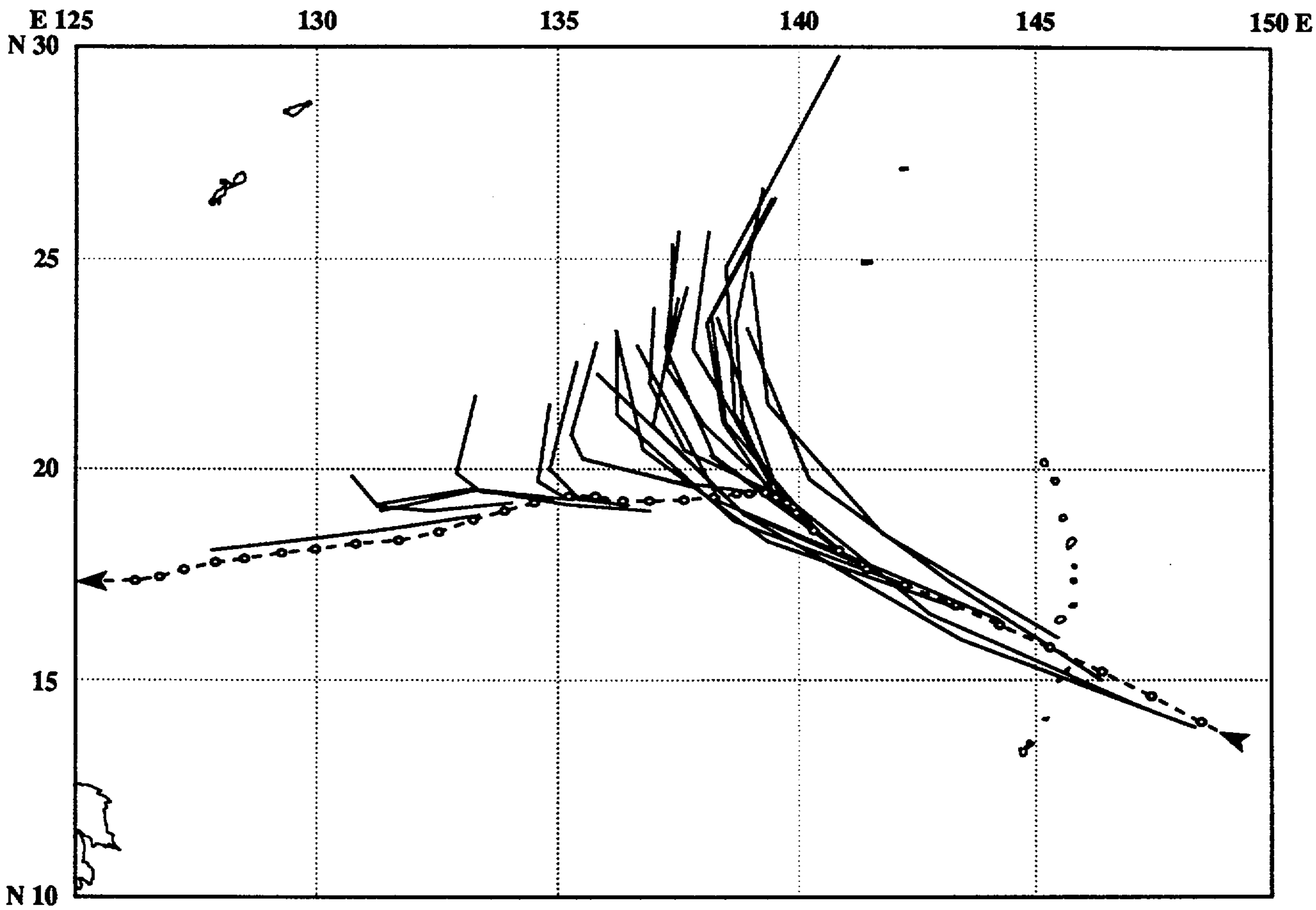
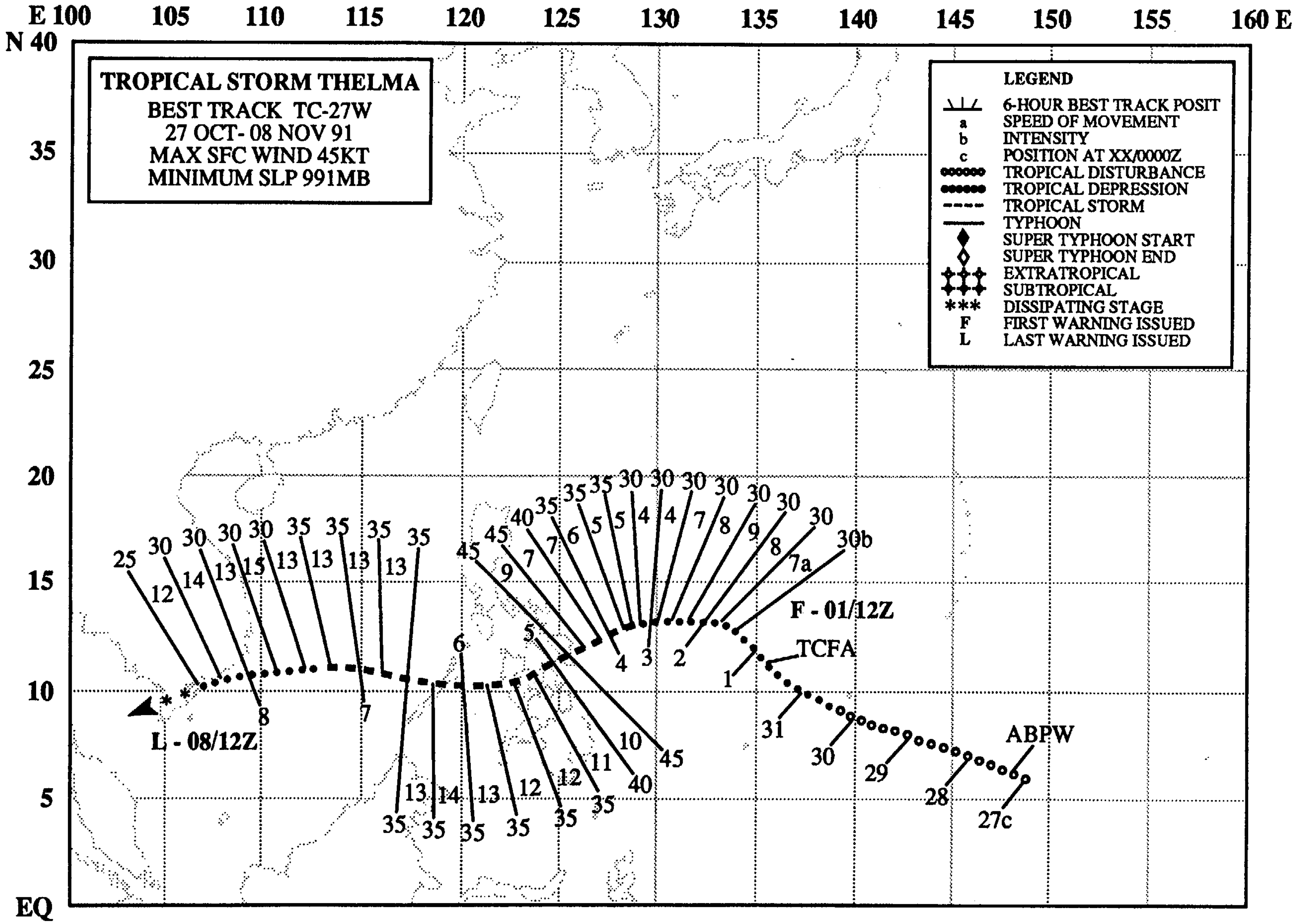


Figure 3-26-2. JTWC forecasts, when compared to the final best track, show gradual improvement after the bifurcation point near 140°E.


TROPICAL STORM THELMA
BEST TRACK TC-27W
27 OCT- 08 NOV 91
MAX SFC WIND 45KT
MINIMUM SLP 991MB
LEGEND
6-HOUR BEST TRACK POSIT
a SPEED OF MOVEMENT
b INTENSITY
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
F - 01/12Z
TCFA
ABPW
L - 08/12Z
E 100
105
110
115
120
125
130
135
140
145
150
155
160 E
N 40
35
30
25
20
15
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5
EQ

TYPHOON THELMA (27W)

I. HIGHLIGHTS

The worst loss of life due to a natural disaster in the western North Pacific during 1991 occurred when Tropical Storm Thelma made landfall in the Visayan Islands of the Philippines. News accounts estimated that 6000 people died and 20,000 people were left homeless by catastrophic events resulting from the passage of the tropical storm including the failure of a dam, landslides and extensive flash flooding. The highest casualties occurred at Ormoc on Leyte Island where widespread logging in recent years had stripped the hills above the port city bare of vegetation.

II. TRACK AND INTENSITY

Thelma began as a tropical disturbance in the eastern Caroline Islands, and was first mentioned on the 270600Z October Significant Tropical Weather Advisory. After persisting for 4 days, its convection rapidly increased, the system center reorganized, and JTWC forecasters issued a Tropical Cyclone Formation Alert at 311900Z. A satellite-derived intensity estimate of 25 kt (13 m/sec) prompted issuance of the first warning at 011200Z November. A week after being first detected, Thelma developed into a tropical storm at 031200Z, and headed west-southwestward for the Philippine island of Samar. Torrential rains dumped an estimated 6 inches (150 mm) of water in 24 hours on the central Philippines before Thelma moved into the South China Sea. The cloud system was unable to reintensify over water due to vertical wind shear (Figure 3-27-1). The final warning was issued at 081200Z as Thelma made landfall over Vietnam's Mekong River Delta.

III. FORECAST PERFORMANCE

Initial track forecasts erroneously predicted recurvature into the westerlies north of the axis of the subtropical ridge (Figure 3-27-2). Objective forecast guidance available at the time when it was most needed to support the warning was split between recurvature and non-recurvature forecasts. In retrospect, the beta advection models showed limited skill in an early prognosis of the west-southwestward motion that occurred from 2 through 6 November.

VI. IMPACT

Thelma was the major catastrophe for the Philippine Islands for 1991 in terms of lost lives, surpassing the Mount Pinatubo eruption. Approximately 6000 people died and 20,000 were left homeless.

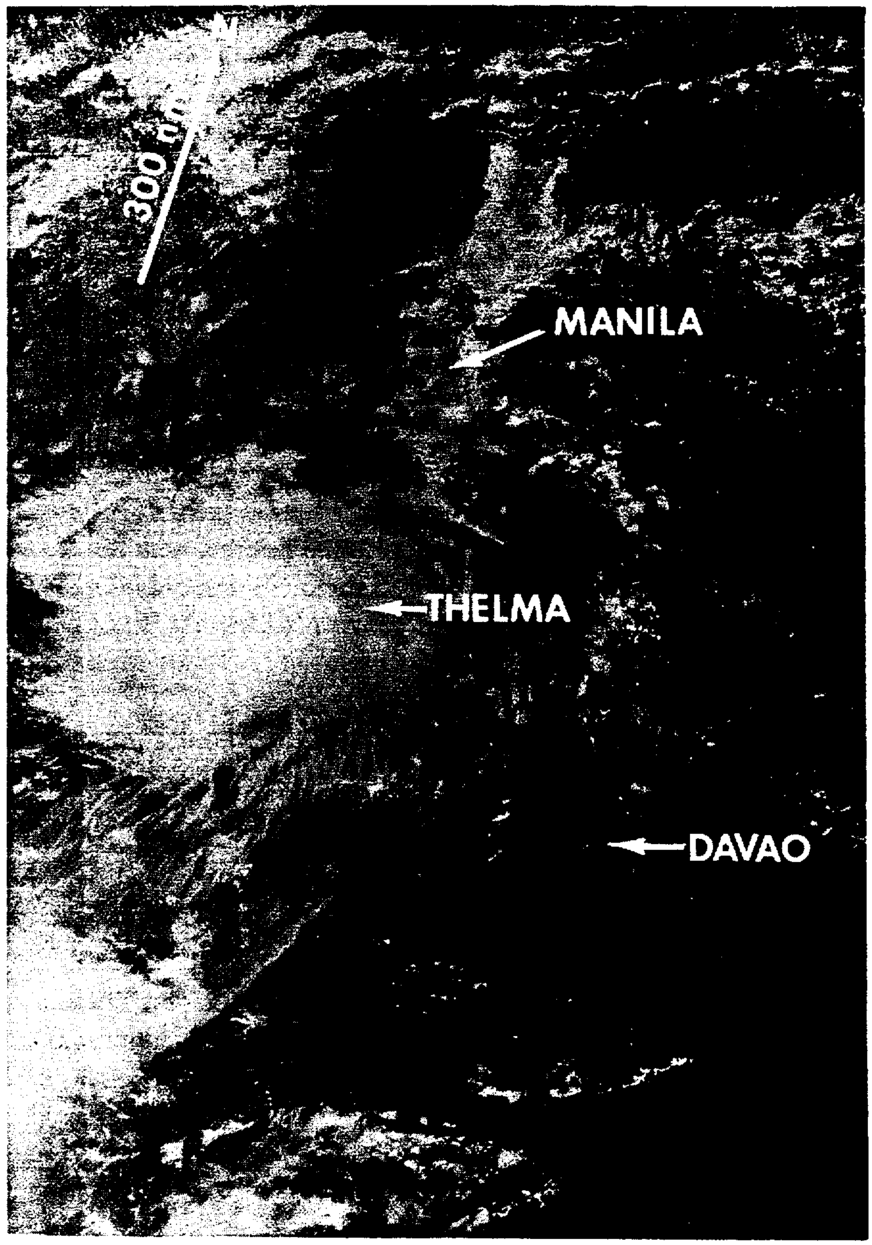


Figure 3-27-1. Thelma enters the South China Sea, but vertical wind shear prevents reintensification (060028Z November DMSP visual imagery).

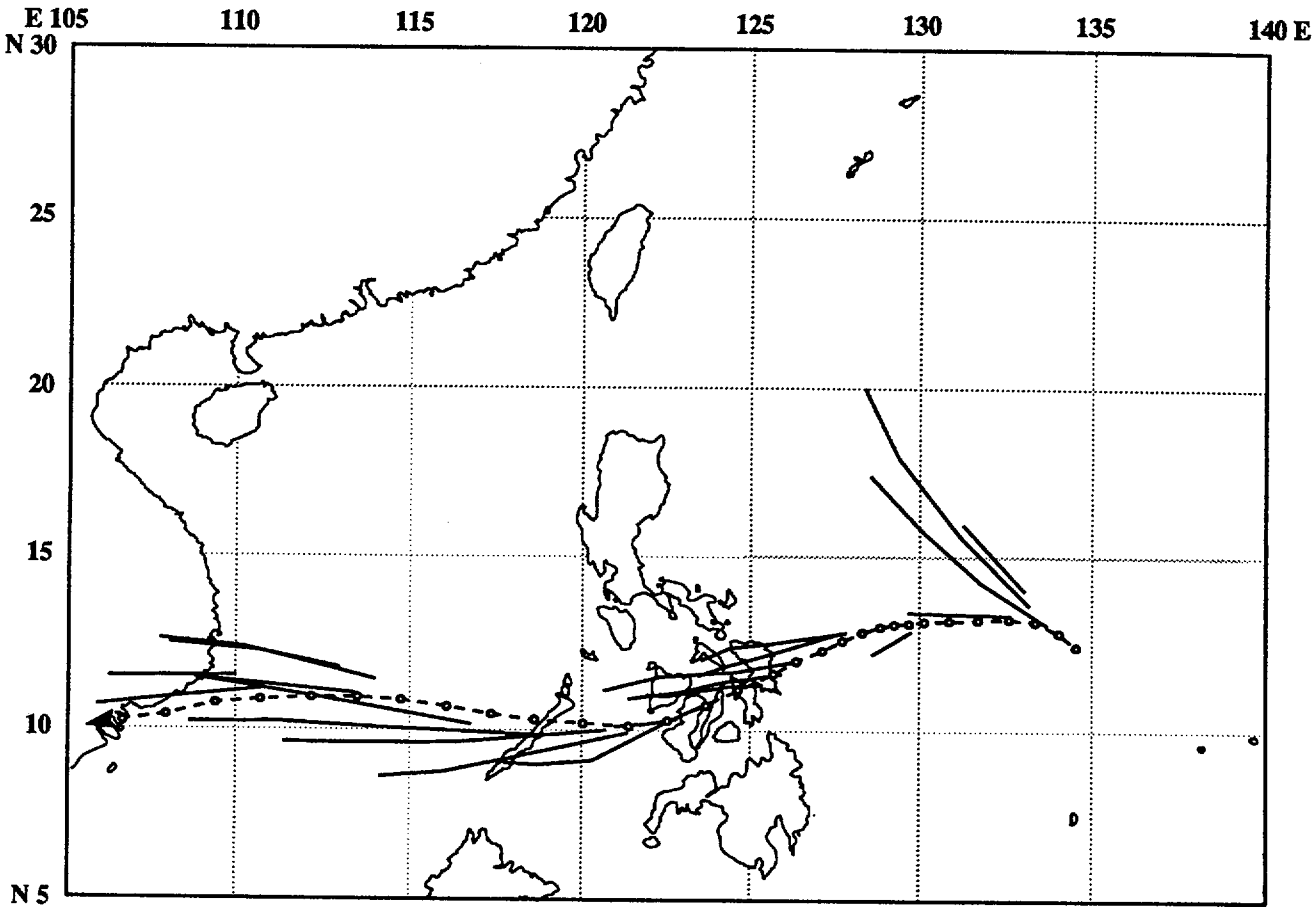
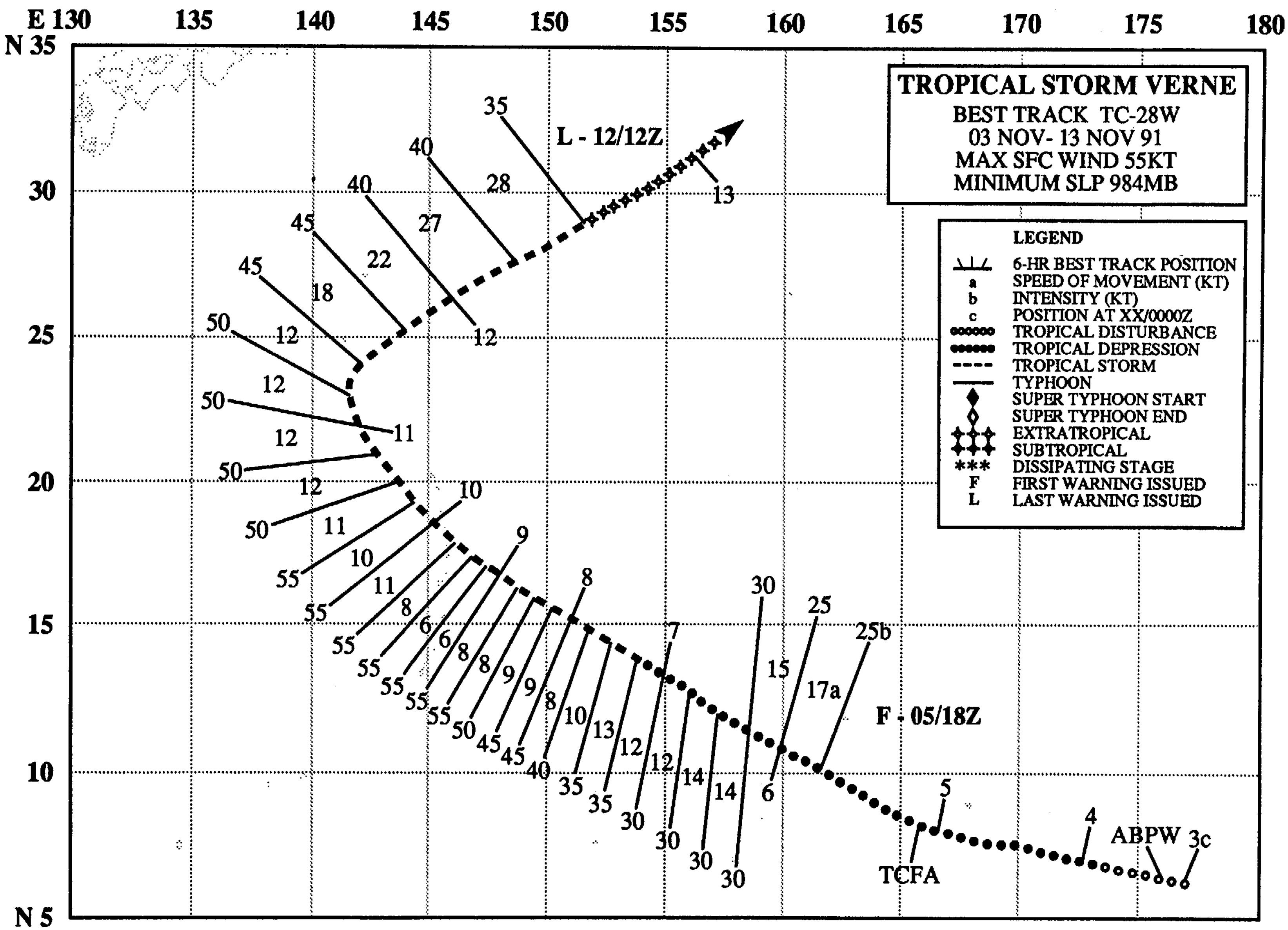


Figure 3-27-2. Comparison of the JTWC official forecasts to the final best track.


TROPICAL STORM VERNE
BEST TRACK TC-28W
03 NOV- 13 NOV 91
MAX SFC WIND 55KT
MINIMUM SLP 984MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 130
135
140
145
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155
160
165
170
175
180
N 35
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15
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N 5
L - 12/12Z
F - 05/18Z
TCFA
ABPW

TROPICAL STORM VERNE (28W)

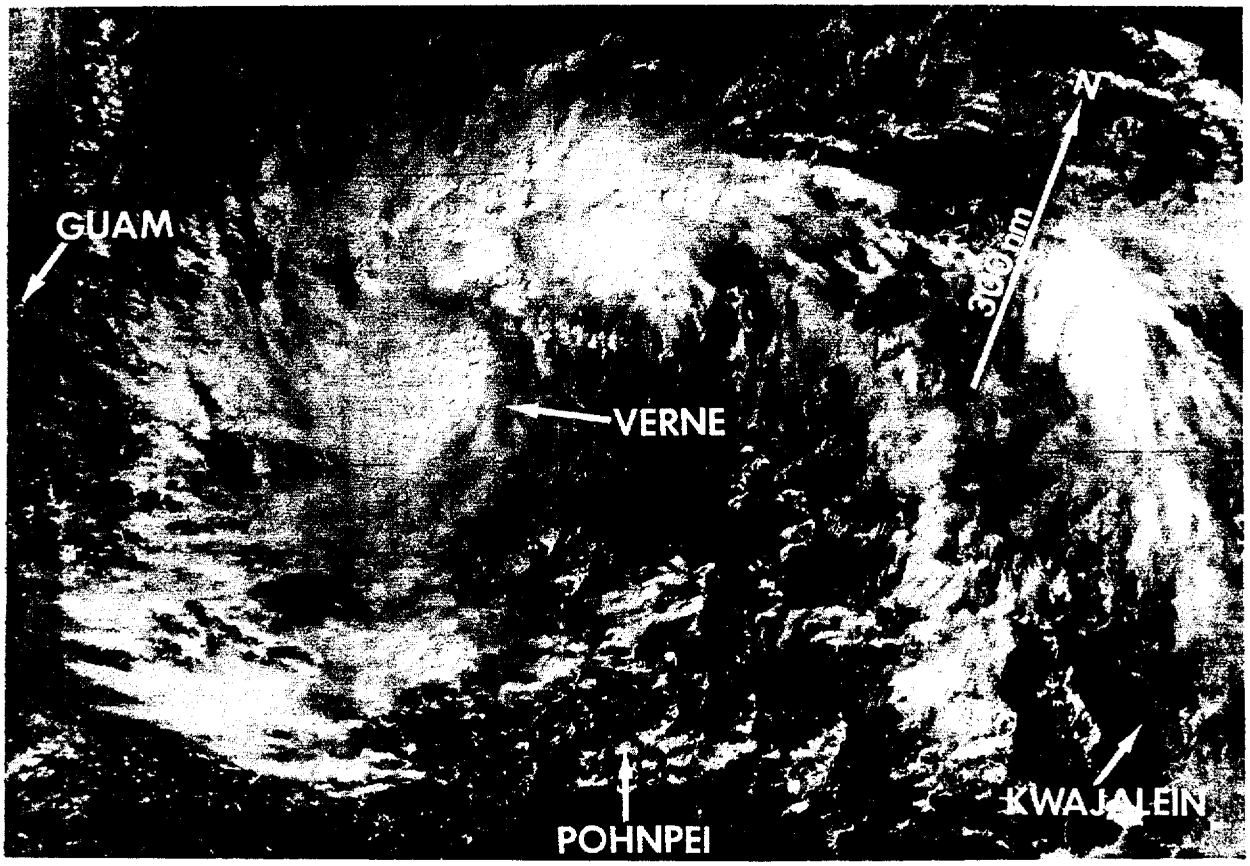
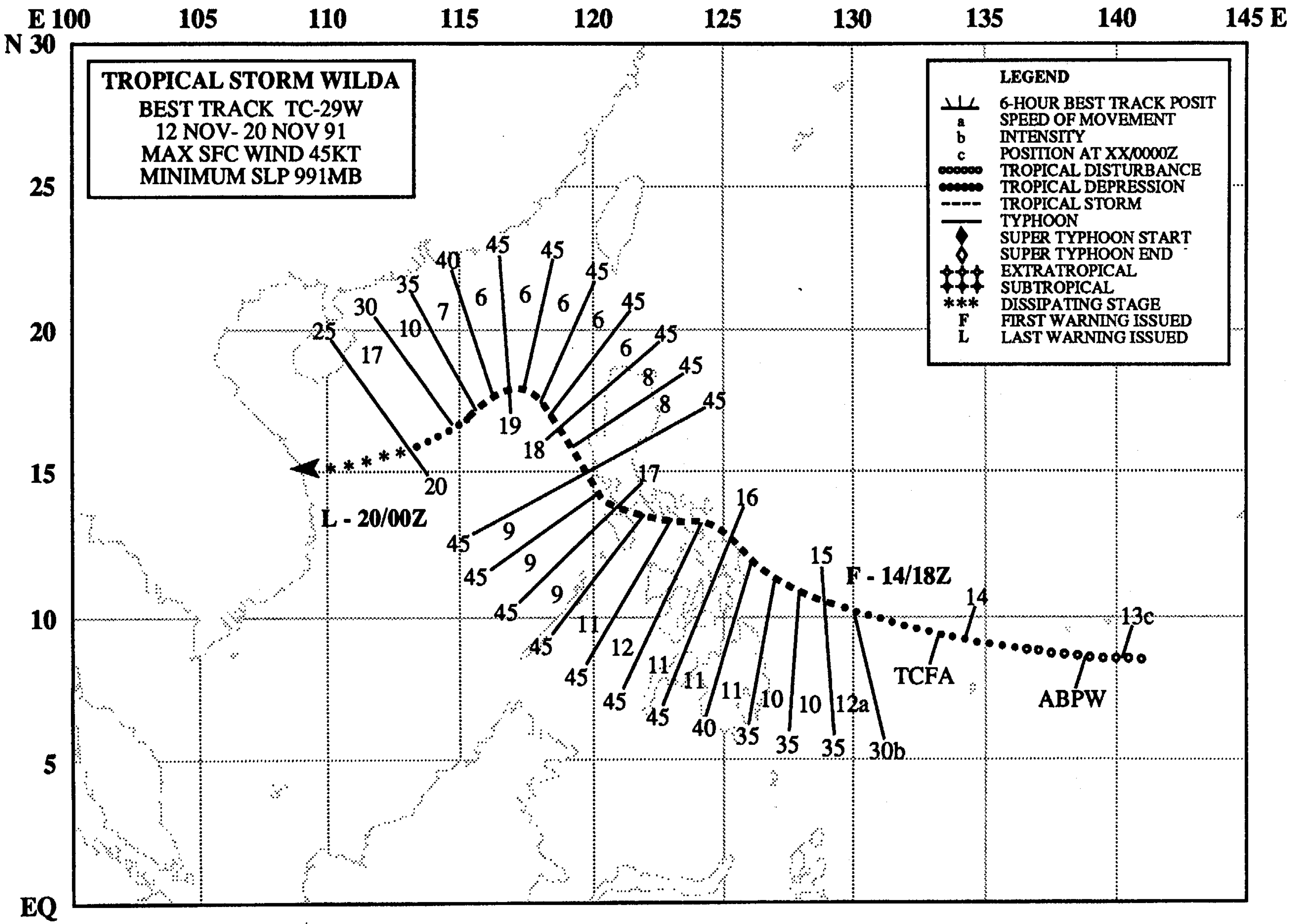


Figure 3-28-1 The partially exposed low-level center of Tropical Storm Verne, located 600 nm (1110 km) east of Guam (062225Z November DMSP visual imagery).

Westerly gradient-level winds along the equator and a persistent cloud system near the international date line on 3 November indicated the potential for further development of a tropical disturbance. Two days after the initial comment about this disturbance on the 030600Z Significant Tropical Weather Advisory, a steady drop of surface pressures in the Marshall Islands convinced forecasters to issue a Tropical Cyclone Formation Alert at 050330Z. Improved convective organization prompted the first warning on Tropical Depression 28W at 051800Z. As the depression tracked west-northwestward, persistent upper-level shear on the east side of the convective cloud mass prevented significant intensification. The shear resulted from a massive upper-level anticyclone located 300 nm (555 km) to the north-northeast of the tropical cyclone. Verne was upgraded to a tropical storm at 071200Z, based on a satellite intensity estimate of 35 kt (18 m/sec). Tropical Storm Verne passed between Pagan and Agrihan Islands in the Northern Marianas with a maximum intensity of 55 kt (28 m/sec), and closed to within 800 nm (1480 km) of Super Typhoon Seth (26W) on 10 November before recurving northeastward on 11 November. The final warning was issued at 121200Z when satellite imagery indicated Verne had transitioned into an extratropical low.



TROPICAL STORM WILDA
BEST TRACK TC-29W
12 NOV- 20 NOV 91
MAX SFC WIND 45KT
MINIMUM SLP 991MB
LEGEND
6-HOUR BEST TRACK POSIT
SPEED OF MOVEMENT
INTENSITY
POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
L - 20/00Z
F - 14/18Z
TCFA
ABPW

TROPICAL STORM WILDA (29W)

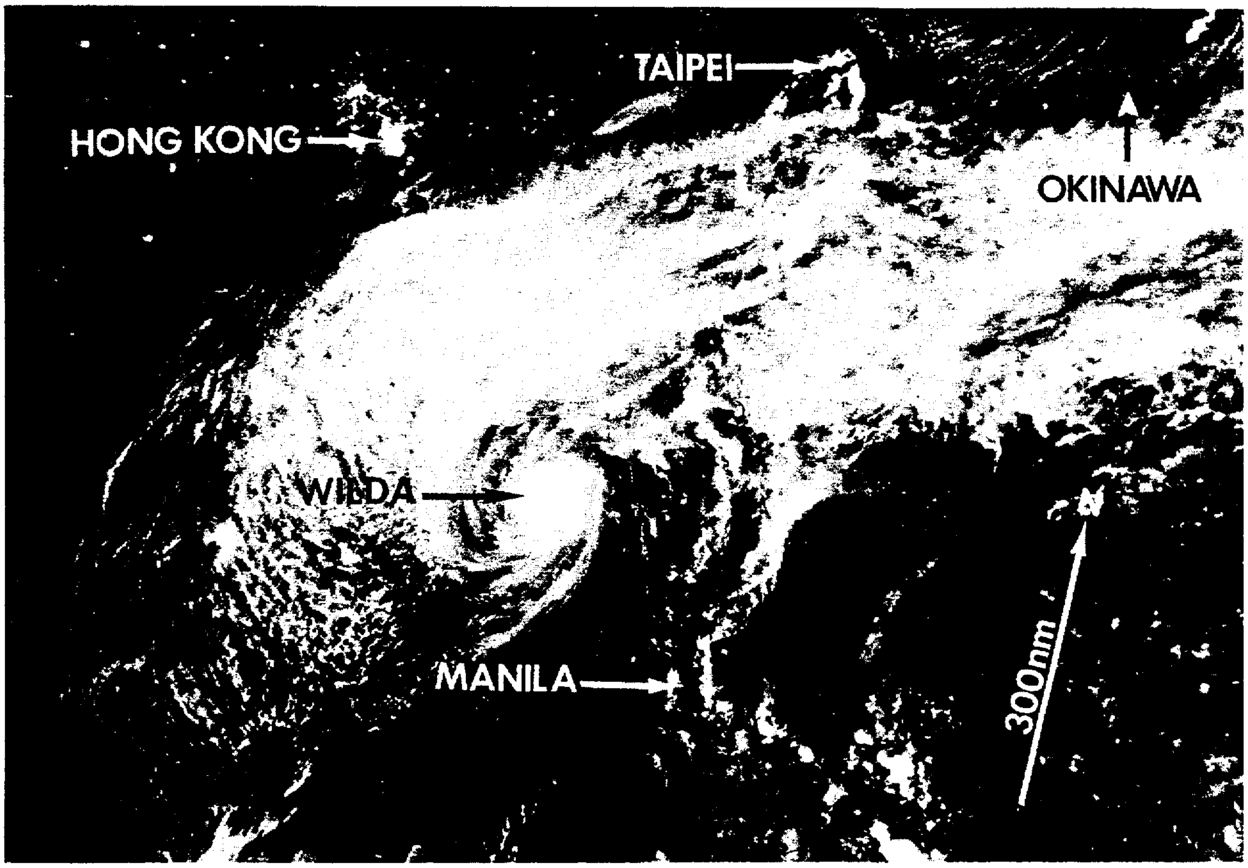
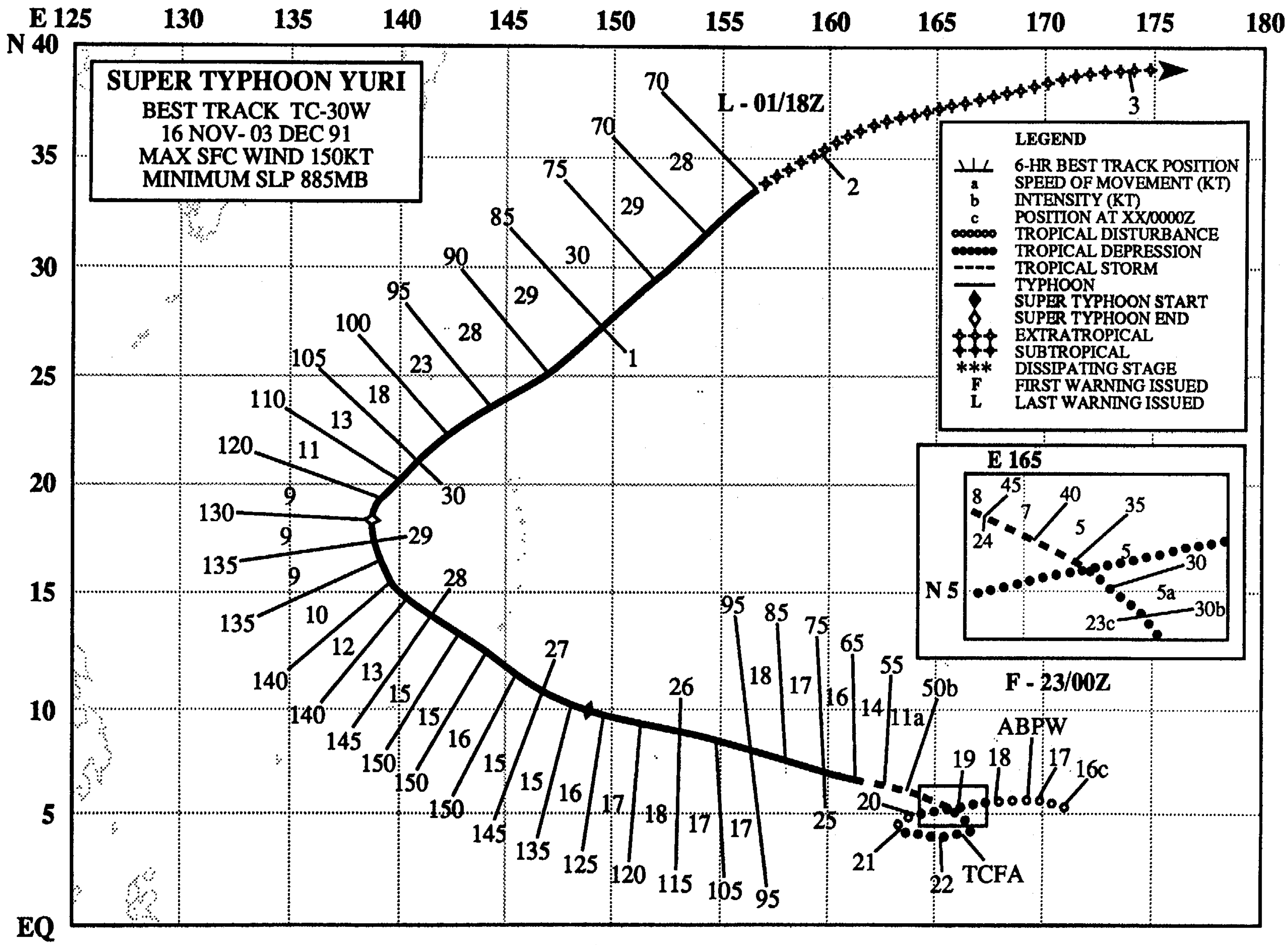


Figure 3-29-1 Tropical Storm Wilda interacts with the northeast monsoon in the South China Sea (181200Z November DMSP moonlight visual imagery).

Tropical Storm Wilda was a midget tropical cyclone, and posed a serious threat to the same central Philippine Islands which were devastated by torrential rains from Tropical Storm Thelma (27W) two weeks earlier. Wilda was initially mentioned on the 130600Z November Significant Tropical Weather Advisory as a small area of persistent deep convection. At 140400Z, JTWC issued a Tropical Cyclone Formation Alert when the system showed a steady increase in convective organization. The first warning followed at 141800Z, based on a Dvorak intensity estimate of 30 kt (15m/s). Wilda continued to intensify as it approached the central Philippines, reaching a peak intensity of 45 kt (23 m/sec) north of Samar. Wilda maintained its peak intensity as it tracked across southern Luzon, passing about 40 nm (75 km) south of Manila at 170400Z. Due to its compact wind field, damage was minimal near Manila. After turning northwestward on 17 November, Wilda began to weaken. The cloud system lost most of its deep convection on 19 November, and the residual low-level circulation drifted southwestward with the prevailing northeast monsoon. The final warning was issued at 200000Z when satellite imagery indicated the system had dissipated.



SUPER TYPHOON YURI
BEST TRACK TC-30W
16 NOV- 03 DEC 91
MAX SFC WIND 150KT
MINIMUM SLP 885MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L - 01/18Z
F - 23/00Z
ABPW
TCFA
E 165
N 5
E 125
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135
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175
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N 40
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EQ

SUPER TYPHOON YURI (30W)

I. HIGHLIGHTS

Super Typhoon Yuri was the most intense tropical cyclone of the year, with maximum sustained winds estimated at 150 kt (77 m/sec) and an estimated minimum sea-level pressure of 885 mb. It also was the closest approach to Guam of a cyclone of this intensity since Super Typhoon Karen (1962). Yuri's normal (verses rapid) rate of intensification to a super typhoon was unusual. High water and massive waves caused extensive damage to coastal areas in the southeastern part of Guam.

II. TRACK AND INTENSITY

Low-level westerly winds along the equator extended eastward to the international date line in mid-November. On 16 November, a marked increase in deep convection occurred near 5°N between 160°E and 175°E, and the area was first mentioned on the Significant Tropical Weather Advisory at 170600Z. This tropical disturbance moved slowly westward at about 6°N until it executed a slow counterclockwise loop east of Kosrae in the eastern Caroline Islands between 19 and 23 November. During these five days, convective organization fluctuated about a slow trend toward improved organization. JTWC issued a Tropical Cyclone Formation Alert at 220900Z. The first warning on Tropical Depression 30W was issued at 230000Z, based on a further improvement in convective organization. Twelve hours later, the tropical cyclone was upgraded to a tropical storm when the satellite signature from the Dvorak Technique indicated maximum winds were 35 kt (18 m/sec). Yuri continued to intensify as it accelerated west-northwestward, and reached typhoon intensity 180 nm (335 km) east of Pohnpei at 241800Z. At this time Yuri was about 300 nm (555 km) in diameter, the size of an "average" typhoon. Pohnpei, (WMO 91348) reported a minimum sea-level pressure of 989 mb and a peak wind gust of 64 kt (33 m/sec) when the eye of the typhoon passed 45 nm (85 km) to the north at 250540Z.

On 26 November, as Yuri approached the western periphery of the subtropical ridge axis, it turned slightly toward the northwest and became a super typhoon at 261500Z. The rate of intensification during the 72-hour period from 240600Z to 270600Z was unusual. Unlike most super typhoons which experience an 18- to 30-hour period of rapid or explosive deepening, Yuri's intensity developed steadily at a rate of about 35 kt (18 m/sec) per day. Based on the satellite analyst's current intensity estimate, it reached a peak intensity of 150 kt (77 m/sec) at 270600Z. Yuri grew rapidly in size, reaching 600 nm (1110 km) in diameter, as it approached Guam.

Super Typhoon Yuri posed an extremely serious threat to Guam. Because of its close proximity to the island and a forward motion in excess of 15 kt (28 km/hr), a small change in direction could have rapidly changed the projected closest point of approach to the island resulting in a direct hit with short notice. Fortunately for the people of Guam, the center of the cyclone passed 55 nm (100 km) south of the southern tip of the island. Maximum sustained winds reported on Guam were 80 kt (42 m/sec) with gusts to 100 kt (51 m/sec) in Apra Harbor. The maximum sustained (over water) winds near southern Guam were estimated to be 100 kt (51 m/sec), gusting to 125 kt (64 m/sec).

After passing the Mariana Islands, the super typhoon (Figure 3-30-1) turned northward, and began to slowly weaken as it rounded the western portion of the subtropical ridge. By this time Yuri's size had grown to a massive diameter of 900 nm (1665 km). After its point of recurvature at 290600Z, Yuri was downgraded to a typhoon. North of 20°N latitude, the typhoon accelerated northeastward and gradually transitioned into an intense, late fall extratropical low pressure system. JTWC's final warning

was issued on 1 December at 1800Z when satellite imagery revealed a significant decrease in convection near the cyclone's center.

III. FORECAST PERFORMANCE

The sequence of JTWC track forecasts correctly predicted Super Typhoon Yuri would pass south of Guam and follow a typical late season recurvature track by turning northward between 135°E and 140°E (Figure 3-30-2). Early warnings on the tropical cyclone had difficulty predicting

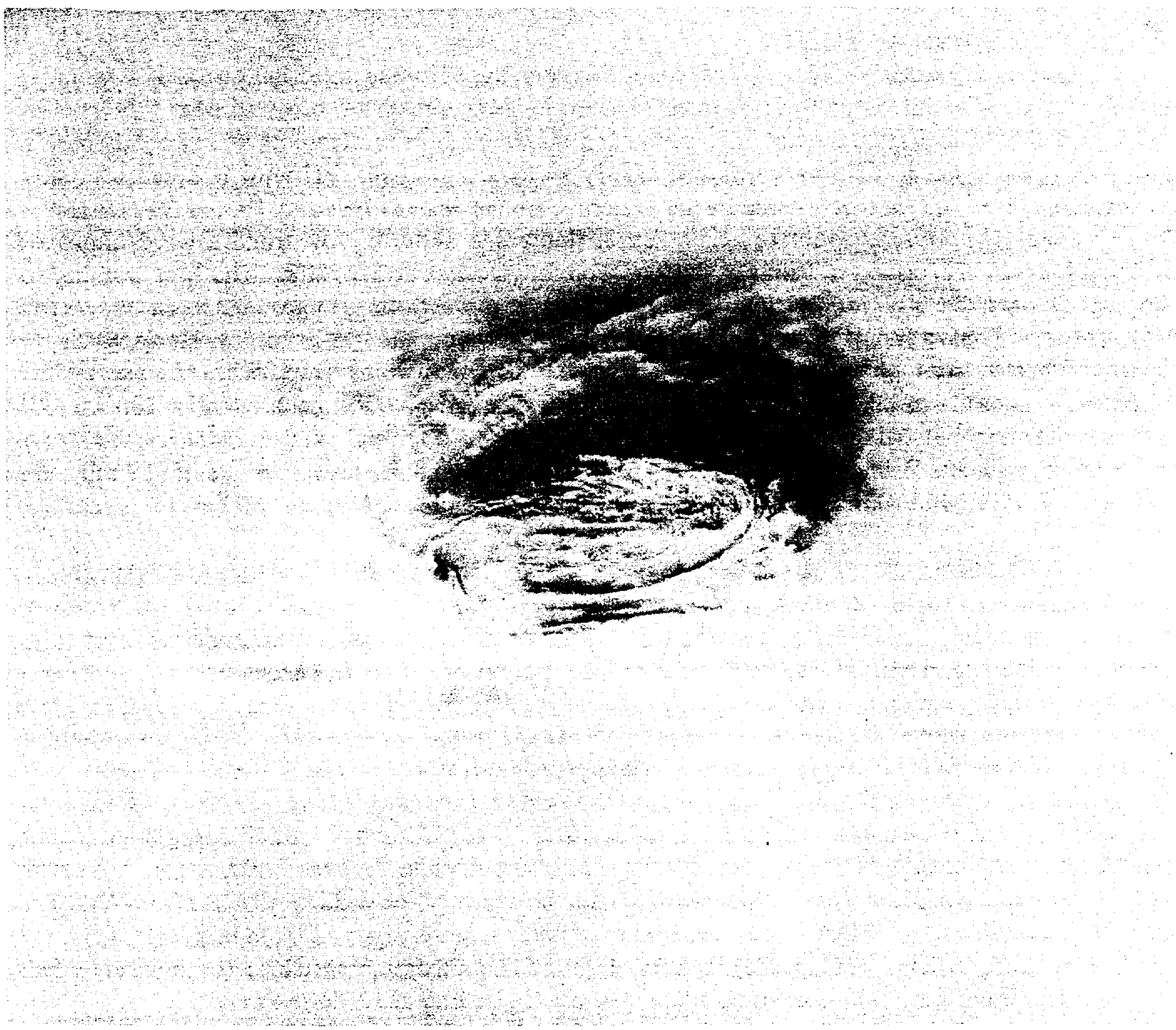


Figure 3-30-1. A spectacular telephoto image from the NASA Space Shuttle Atlantis' mission STS-44 of Super Typhoon Yuri at 145 kt (75 m/sec). Note the cyclonically curved stratocumulus clouds in the high horizontal speed shear zone near the edge of the eye wall (280404Z November photograph courtesy of NASA, Lyndon B. Johnson Space Center, Houston, Texas).

translational motion, since the typhoon accelerated from 5 kt (9 km/hr) on the 23 November to 18 kt (33 km/hr) on 25 November. Although the system continued to accelerate west-northwestward near Pohnpei, JTWC forecast guidance and the warnings based on it, indicated the typhoon would slow as it neared the Marianas. Consequently, early in the week, residents on Guam expected Yuri would make its closest approach on Thanksgiving Day (28 November). Once the forward motion was established, JTWC track forecasts proved to be very accurate as the super typhoon approached Guam. Although JTWC predicted that Yuri would be near super typhoon intensity as it neared Guam, intensity forecasts were a problem. Super typhoon intensity was not expected to occur since the rapid or explosive deepening episode normally associated with super typhoons had not been observed. JTWC also had considerable problems predicting the growth in size of Yuri, as it expanded in size from 300 nm (555 km) to over 900 nm (1665 km) in a little over three days.

Ten hours before Yuri reached its closest point of approach to Guam, NOCC/JTWC recommended that Guam Civil Defense evacuate the southeast coast since inundation exceeding 20 feet (8 m) was expected.

While the forecast performance was only slightly better than average, the warning service provided by NOCC/JTWC was excellent. Yuri's potential to inch closer to Guam, its depiction as an "extremely dangerous storm," and its ability to produce very high waves were passed to residents in hourly updates to the media, convincing people in vulnerable areas to evacuate. This action and the populations appropriate response prevented the loss of lives.

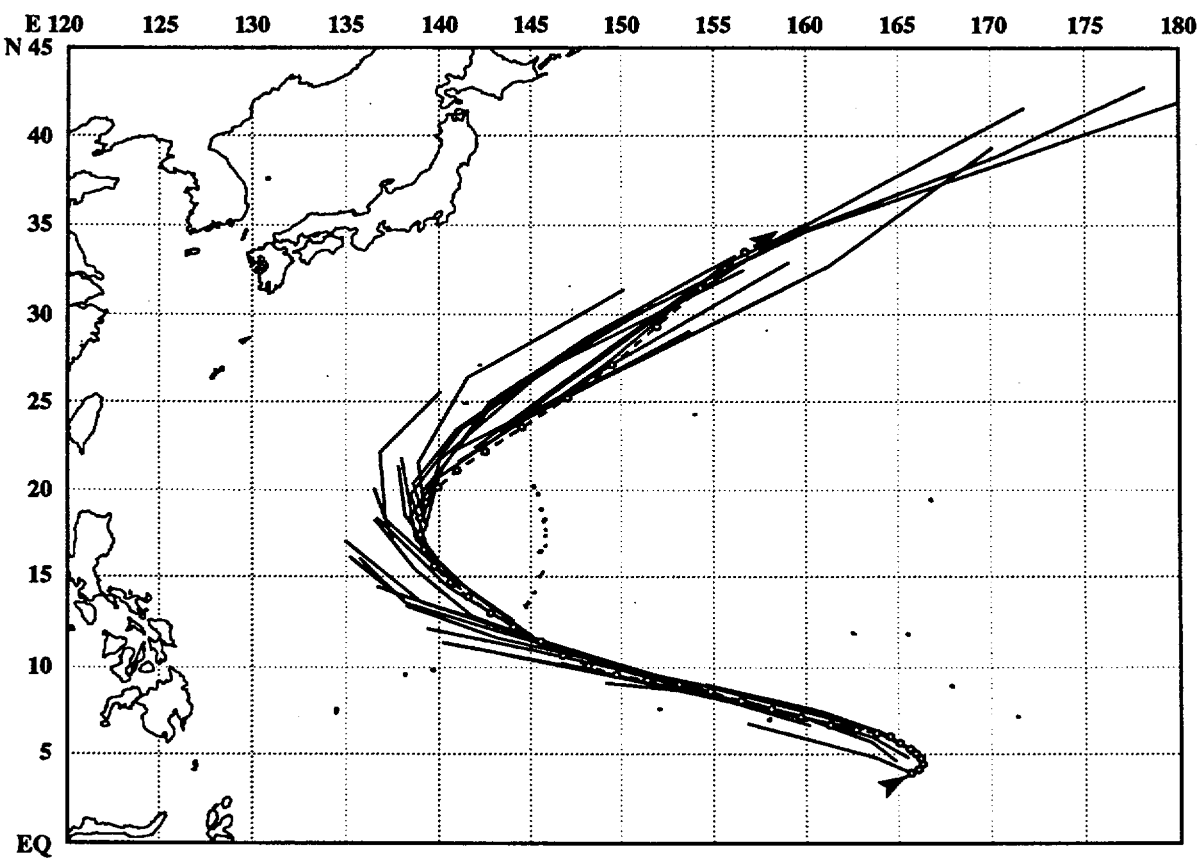


Figure 3-30-2. Summary of JTWC forecasts (solid line) superimposed on Yuri's final best track (dashed line).

IV. IMPACT

An estimated total of $33 million in damage was attributed to Super Typhoon Yuri on Guam, primarily the result of flooding along the southeastern coast. By making its closest point of approach at high tide, the combined effects of a large translational speed, massive size, super typhoon intensity and the cyclone's center location south of Guam exposed the island to a prolonged period of northeasterly winds. This created ideal conditions for extreme surf on the eastern side of the island. Waves in excess of 30 ft (12 m) battered the southeastern coastline. Estimates of high water levels and wave run up at high energy areas with little or no protecting reef flats are shown in Figure 3-30-3. Some of these areas experienced inundation two to three times greater than with Typhoon Russ (1990), 11 months earlier.

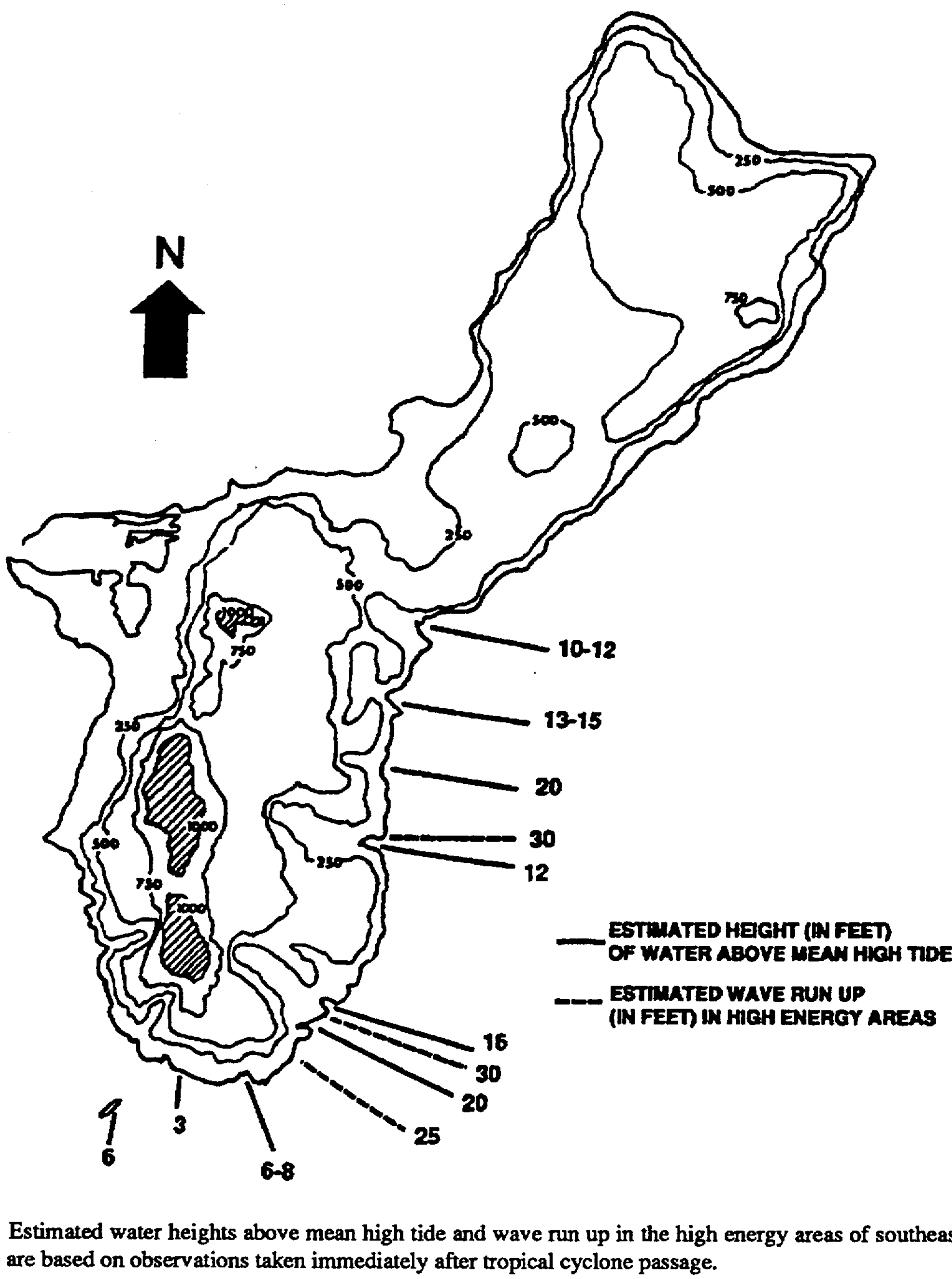
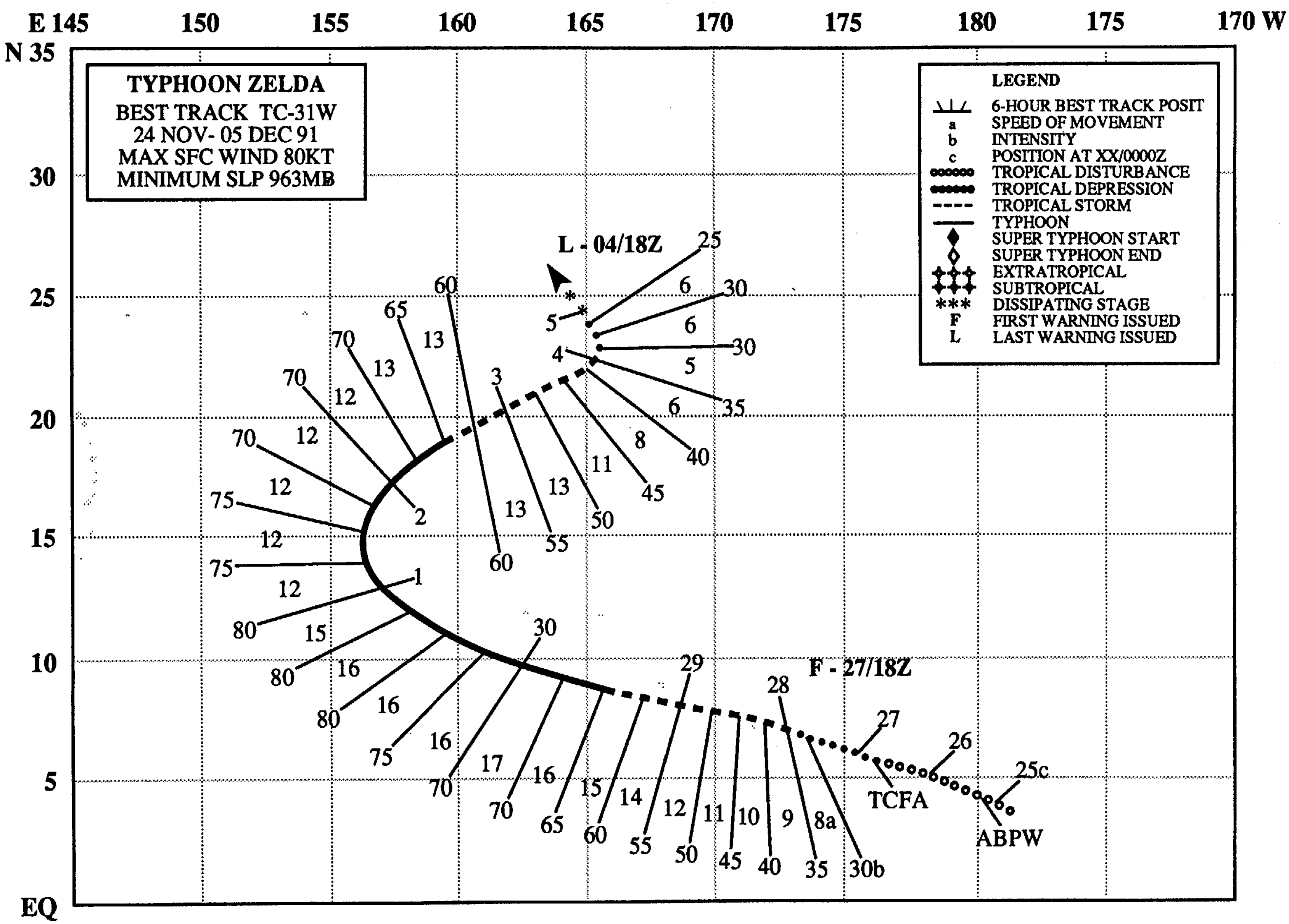


Figure 3-30-3. Estimated water heights above mean high tide and wave run up in the high energy areas of southeastern Guam. Estimated values (in feet) are based on observations taken immediately after tropical cyclone passage.

Yuri's disastrous combination of high water effects caused much greater inundation, reef damage and beach erosion to the island's low-lying beaches and bays along the southeast coastline. Sixty-two homes were totally destroyed; another 207 had major damage; and 348 sustained minor damage. Damage estimates included $19.1 million to public facilities and infrastructure, $10.8 million to commercial buildings and equipment, $2.5 million to residential structures, and $500,000 to agriculture (Figure 3-30-4). Guam residents were without power and water during the Thanksgiving holiday weekend.

Yuri caused an estimated $3 million in damage on Pohnpei, including the loss of the island's only AM radio station tower. Officials on Rota placed damage estimates at $2 million. There was no loss of life in the Marianas or Pohnpei as a result of the cyclone.

Figure 3-30-4. Yuri's high winds uprooted this large tree and parked it on a car. The more flexible, smaller coconut palms in the background survived (Photograph courtesy of Mrs. Patricia L. Hudson).


TYPHOON ZELDA
BEST TRACK TC-31W
24 NOV- 05 DEC 91
MAX SFC WIND 80KT
MINIMUM SLP 963MB
LEGEND
6-HOUR BEST TRACK POSIT
SPEED OF MOVEMENT
INTENSITY
POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
FIRST WARNING ISSUED
LAST WARNING ISSUED
E 145
150
155
160
165
170
175
180
175
170 W
N 35
30
25
20
15
10
5
EQ
L - 04/18Z
F - 27/18Z
TCFA
ABPW
25c
26
27
28
29
30
30b
8a
1
2
3
4
5

TYPHOON ZELDA (31W)

I. HIGHLIGHTS

Typhoon Zelda was the last tropical cyclone of the year, and may have set a record by being the fifth midget of the year to occur in the western North Pacific. Intensification during the early stages of its development proved difficult to handle because of its very small size. The operations of the missile test range located at Kwajalein and nearby islands and atolls were seriously affected.

II. TRACK AND INTENSITY

Westerly winds along the equator associated with the onset phase of the El Niño phenomenon helped to generate a weak cyclonic circulation near the international date line in late November. At 250600Z, persistent convection near the weak circulation center that was to become Zelda led to its inclusion on the Significant Tropical Weather Advisory. Strong vertical wind shear initially hampered intensification, but improved upper-level outflow at 262100Z indicated the disturbance had good potential for development, prompting a Tropical Cyclone Formation Alert. At 271800Z, the first warning was issued. Over the next 36 hours, Tropical Depression 31W moved west-northwestward and rapidly intensified to minimal typhoon intensity as it moved through the Marshall Islands. Kwajalein (WMO 91366) reported winds gusting to 71 kt (37 m/sec) as the eye of the midget passed 25 nm (45 km) south of the atoll at 290300Z. Zelda was upgraded to a typhoon at 291200Z based on reports from the Automatic Meteorological Observing Station (AMOS) at Ujae (WMO 91365) which measured sustained surface winds of 65 kt (33 m/sec) (Figure 3-31-1). Zelda continued to track west-northwestward, reaching a peak intensity of 80 kt (41 m/sec) at 301200Z approximately 160 nm (295 km) west of Enewetak. Shortly thereafter, a deep trough induced by Super Typhoon Yuri (30W), which

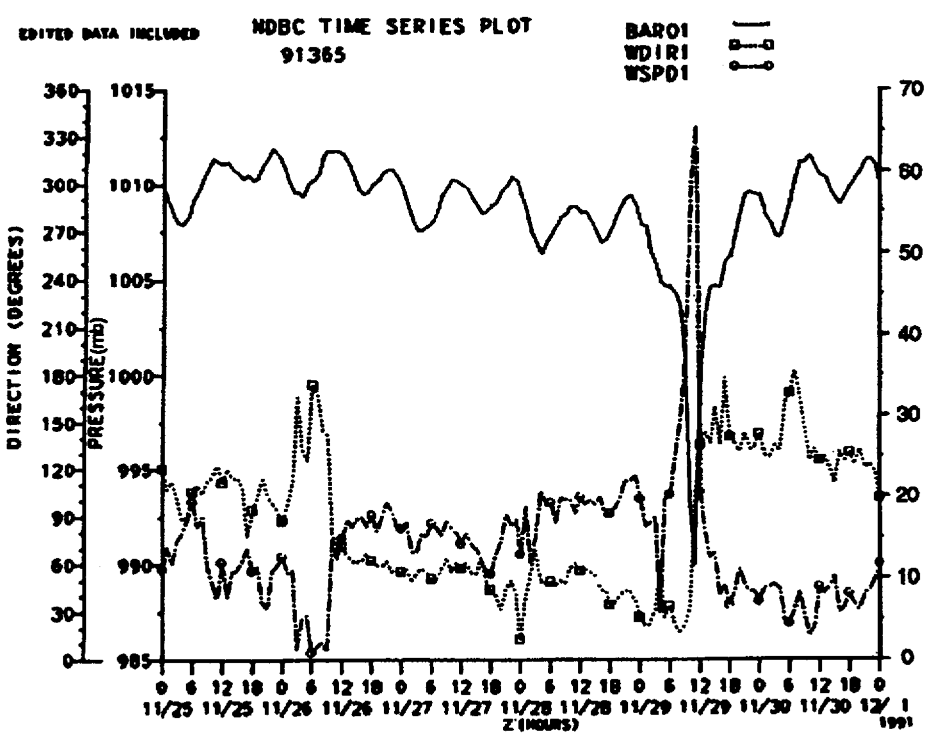


Figure 3-31-1 Time series of wind and pressure observations taken by the Automated Meteorological Observing Station (AMOS) on Ujae Atoll from 250000Z to 302300Z November. Maximum surface winds recorded at 291200Z were 65 kt (33 m/sec), and the minimum pressure dropped to 989 mb (Data courtesy of the National Data Buoy Center).

was about 1000 nm (1850 km) to the northwest, weakened the subtropical ridge, and Zelda turned northward near 157°E (Figure 3-31-2). After recurving, it trailed along a frontal boundary generated by the extratropical remnants of Yuri. As Zelda raced eastward, upper-level winds increased and it's central convection sheared away. The remaining low-level circulation detached from the frontal cloud line and drifted slowly north-northwestward. The final warning on Zelda and the final warning of 1991 was issued on 4 December at 1800Z.

III. FORECAST PERFORMANCE

JTWC's experience with Typhoon Zelda emphasized the difficulties associated with performing infrared satellite analyses of midget tropical cyclones. It underscored the need to use visual and infrared image pairs when available. Due to its small size and seemingly poorly organized outflow pattern, Zelda did not have an impressive infrared satellite signature. Based on a Dvorak intensity estimate of 25 kt (13 m/sec) at 282330Z, the 290000Z warning indicated Zelda was still a tropical depression. But, when radar and synoptic reports from Kwajalein indicated otherwise, the warning was amended to upgrade Zelda to tropical storm intensity. In post-analysis, it is estimated that Zelda actually became a tropical storm at 280000Z, 24 hours earlier and was approaching severe tropical storm intensity as it passed Kwajalein's missile test range, which was caught unprepared by the stronger than forecast winds. Later, Zelda's sharp recurvature track was not anticipated by the JTWC (Figure 3-31-3), and average track forecast errors at 72 hours after 290000Z were 500 nm (925 km).

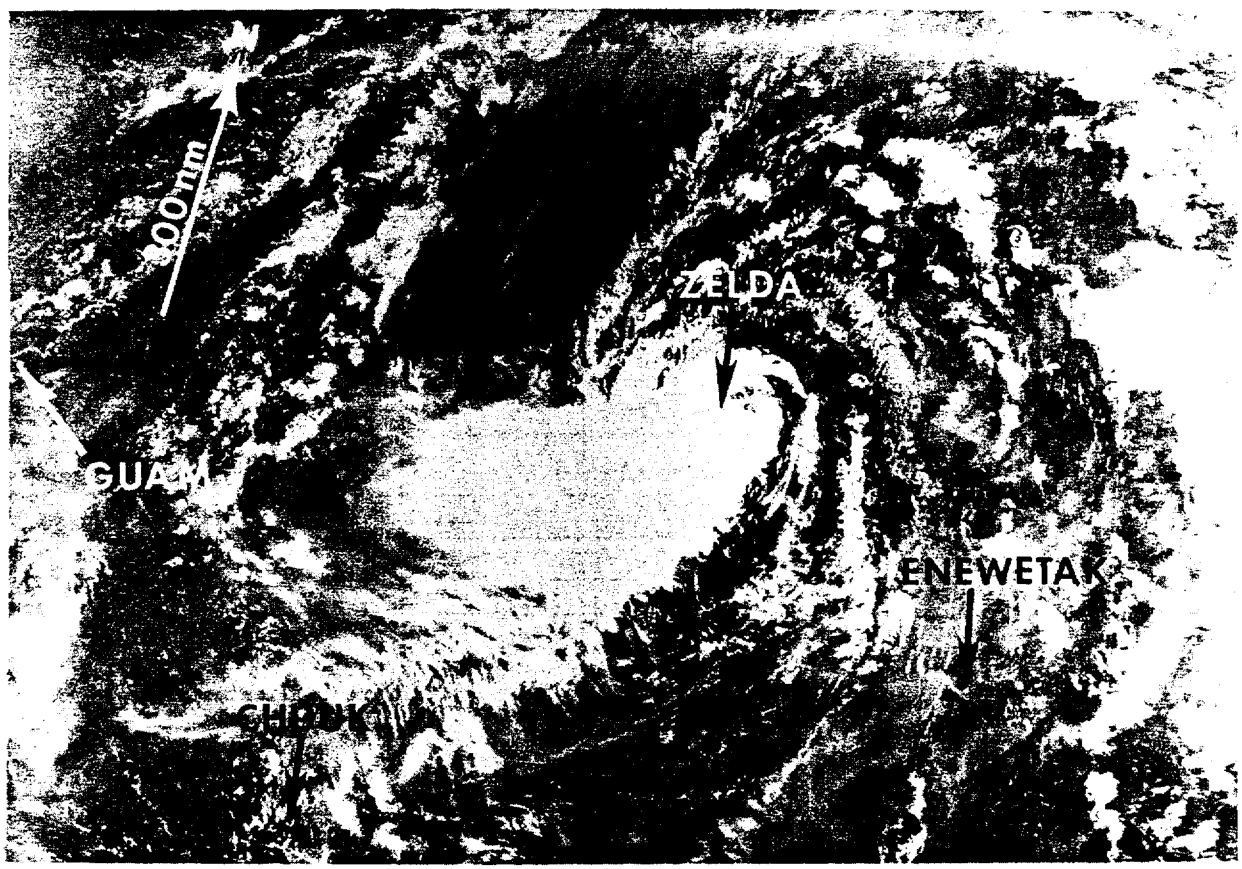


Figure 3-31-2. Typhoon Zelda near its point of recurvature (010903Z December NOAA infrared imagery).

IV. IMPACT

As the Mariana Islands were recovering from giant-sized Super Typhoon Yuri (30W), it was tiny Zelda that left more people homeless and injured. An estimated 5,000 people lost their plyboard and sheet-iron-roofed homes on Ebeye atoll, and 27 people were injured. On 9 December, President Bush signed a major disaster declaration, making Ebeye Island and the atolls of Kwajalein, Lae, and Ujae eligible for federal disaster assistance.

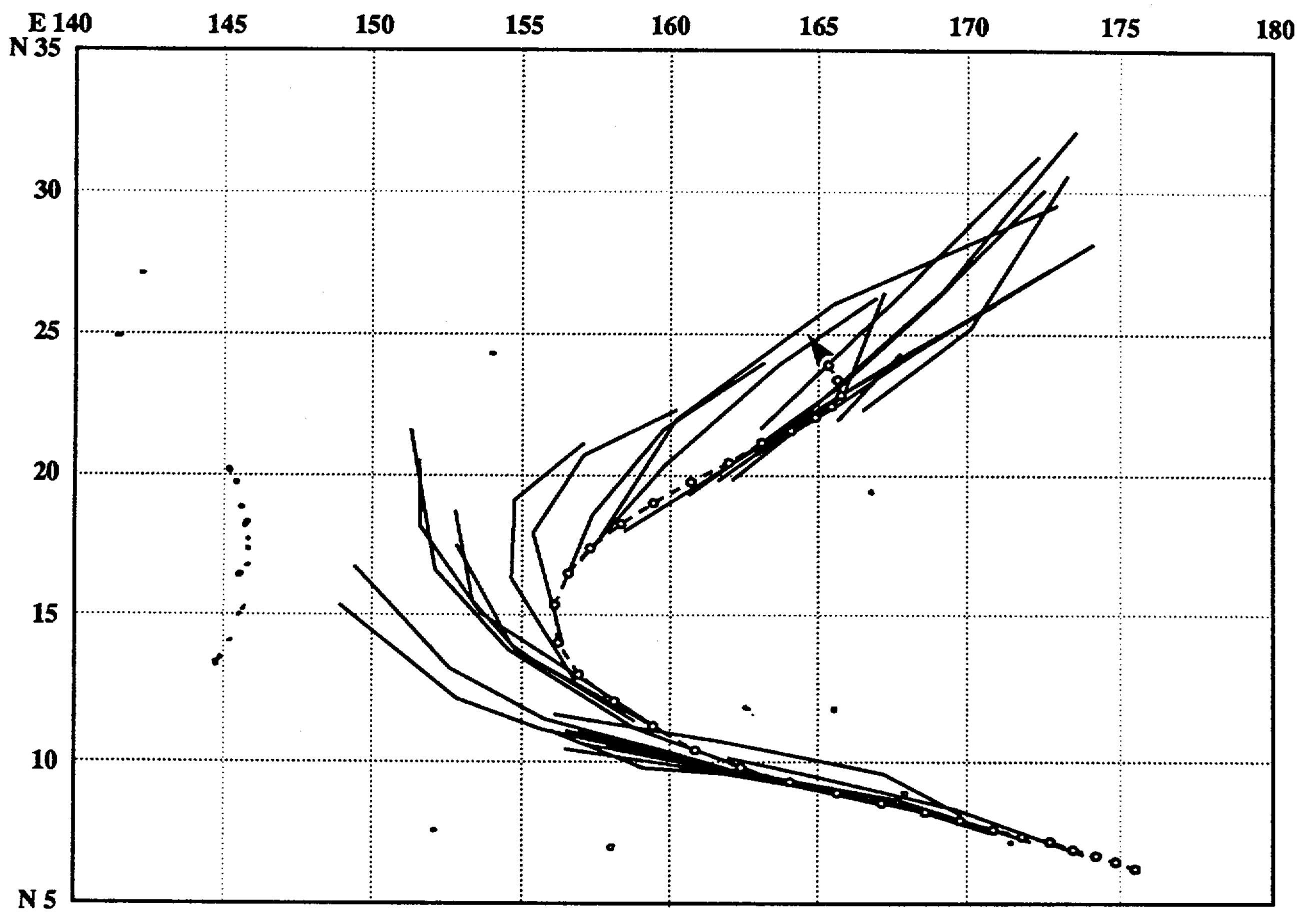


Figure 3-31-3. Comparison of the JTWC official forecasts to the final best track.

3.3 NORTH INDIAN OCEAN TROPICAL CYCLONES

Spring and fall in the North Indian Ocean are periods of transition between major climatic controls and the most favorable seasons for tropical cyclone activity (Tables 3-5 and 3-6). As in 1991, a total of 4 tropical cyclones occurred in the North Indian Ocean, which was close to the long-term average of 4 to 5 per year. The JTWC was in warning status a total of 17 days, and there were no calendar warning days with two or more tropical cyclones.

Tropical Cyclone 01A was a rare January cyclone, the first ever recorded in the Arabian Sea basin. **Tropical Cyclone 02B** was the deadliest and most destructive natural disaster of 1991. A month later, **Tropical Cyclone 03B** caused further damage to the coastline of Bangladesh. In the fall transition season, **Tropical Cyclone 04B** crossed the southern tip of India.

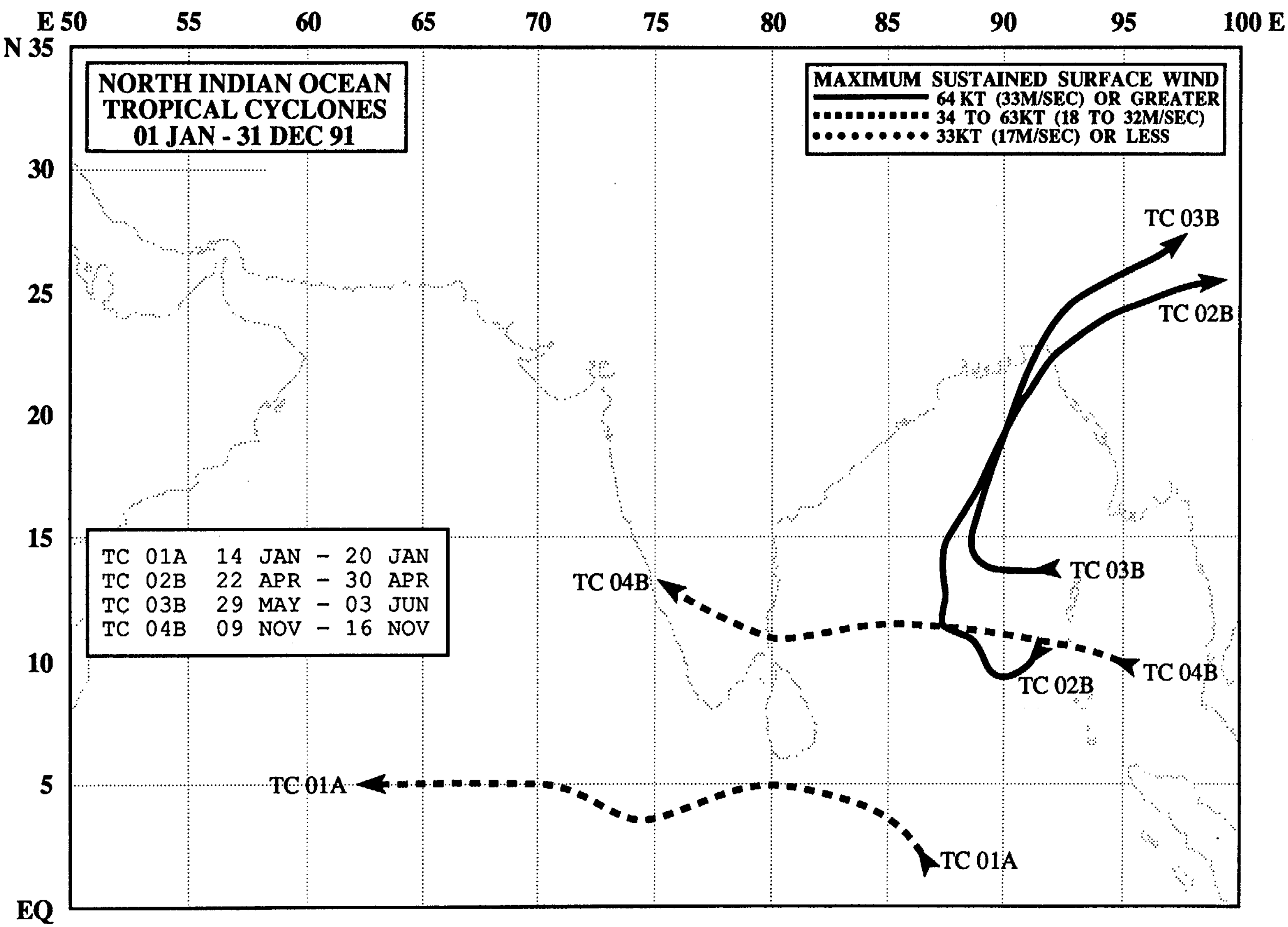
TABLE 3-5. **1991 SIGNIFICANT TROPICAL CYCLONES NORTH INDIAN OCEAN**

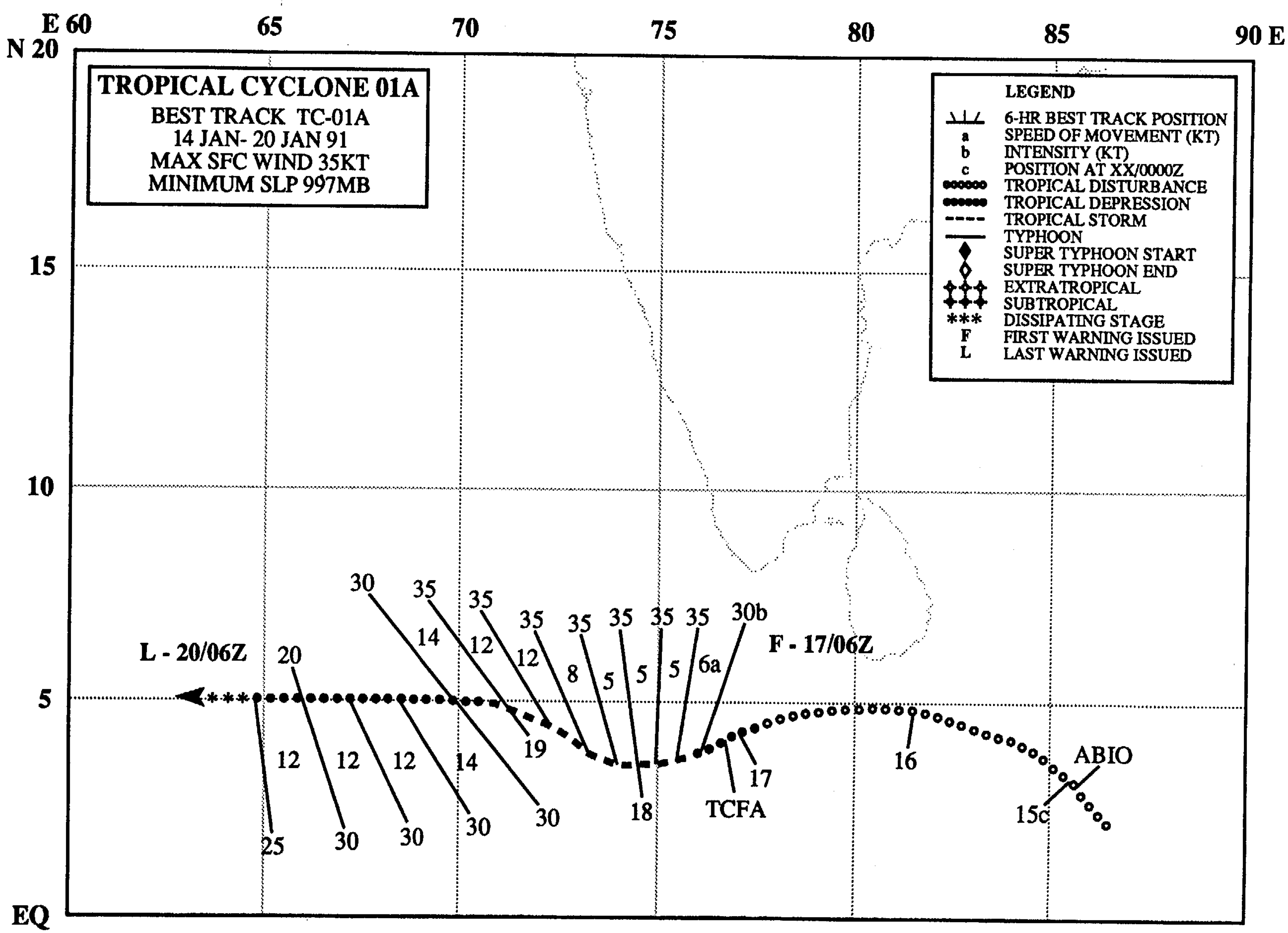
TROPICAL CYCLONE	PERIOD OF WARNING	NUMBER OF WARNINGS ISSUED	MAXIMUM SURFACE WINDS-KT (M/SEC)	ESTIMATED MSLP (MB)
TC 01A	17 JAN - 20 JAN	13	35 (18)	997
TC 02B	24 APR - 30 APR	25	140 (72)	898
TC 03B	31 MAY - 02 JUN	10	50 (26)	987
TC 04B	14 NOV - 16 NOV	8	40 (21)	994
	TOTAL:	56		

TABLE 3-6. **NORTH INDIAN OCEAN TROPICAL CYCLONES DISTRIBUTION**

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1971*	-	-	-	-	-	0	0	0	0	1	1	0	2
1972*	0	0	0	1	0	0	0	0	2	0	1	0	4
1973*	0	0	0	0	0	0	0	0	0	1	2	1	4
1974*	0	0	0	0	0	0	0	0	0	0	1	0	1
1975	1	0	0	0	2	0	0	0	0	1	2	0	6
1976	0	0	0	1	0	1	0	0	1	1	0	1	5
1977	0	0	0	0	1	1	0	0	0	1	2	0	5
1978	0	0	0	0	1	0	0	0	0	1	2	0	4
1979	0	0	0	0	1	1	0	0	2	1	2	0	7
1980	0	0	0	0	0	0	0	0	0	0	1	1	2
1981	0	0	0	0	0	0	0	0	0	1	1	1	3
1982	0	0	0	0	1	1	0	0	0	2	1	0	5
1983	0	0	0	0	0	0	0	1	0	1	1	0	3
1984	0	0	0	0	1	0	0	0	0	1	2	0	4
1985	0	0	0	0	2	0	0	0	0	2	1	1	6
1986	1	0	0	0	0	0	0	0	0	0	2	0	3
1987	0	1	0	0	0	2	0	0	0	1	2	2	8
1988	0	0	0	0	0	1	0	0	0	1	2	1	5
1989	0	0	0	0	1	1	0	0	0	0	1	0	3
1990	0	0	0	1	1	0	0	0	0	0	1	1	4
1991**	1	0	0	1	0	1	0	0	0	0	1	0	4
(1975-1991)													
AVERAGE:	0.2	0.1	0.0	0.2	0.6	0.5	0.0	0.1	0.2	0.8	1.4	0.5	4.5
TOTAL:	3	1	0	3	11	9	0	1	3	14	24	8	77

* JTWC WARNING RESPONSIBILITY BEGAN ON 4 JUNE 1971 FOR THE BAY OF BENGAL, EAST OF 90° EAST LONGITUDE. AS DIRECTED BY CINCPAC, JTWC ISSUED WARNINGS ONLY FOR THOSE TROPICAL CYCLONES THAT DEVELOPED OR TRACKED THROUGH THAT PART OF THE BAY OF BENGAL. IN 1975, JTWC'S AREA OF RESPONSIBILITY WAS EXTENDED WESTWARD TO INCLUDE THE WESTERN PART OF THE BAY OF BENGAL AND THE ENTIRE ARABIAN SEA.


NORTH INDIAN OCEAN
TROPICAL CYCLONES
01 JAN - 31 DEC 91
MAXIMUM SUSTAINED SURFACE WIND
64 KT (33M/SEC) OR GREATER
34 TO 63KT (18 TO 32M/SEC)
33KT (17M/SEC) OR LESS
TC 01A 14 JAN - 20 JAN
TC 02B 22 APR - 30 APR
TC 03B 29 MAY - 03 JUN
TC 04B 09 NOV - 16 NOV
E 50
55
60
65
70
75
80
85
90
95
100 E
N 35
30
25
20
15
10
5
EQ
TC 03B
TC 02B
TC 03B
TC 04B
TC 04B
TC 02B
TC 01A
TC 01A


TROPICAL CYCLONE 01A
BEST TRACK TC-01A
14 JAN- 20 JAN 91
MAX SFC WIND 35KT
MINIMUM SLP 997MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 60
65
70
75
80
85
90 E
N 20
15
10
5
EQ
L - 20/06Z
F - 17/06Z
ABIO
TCFA
30b
6a
15c
16
17
18
19

TROPICAL CYCLONE 01A

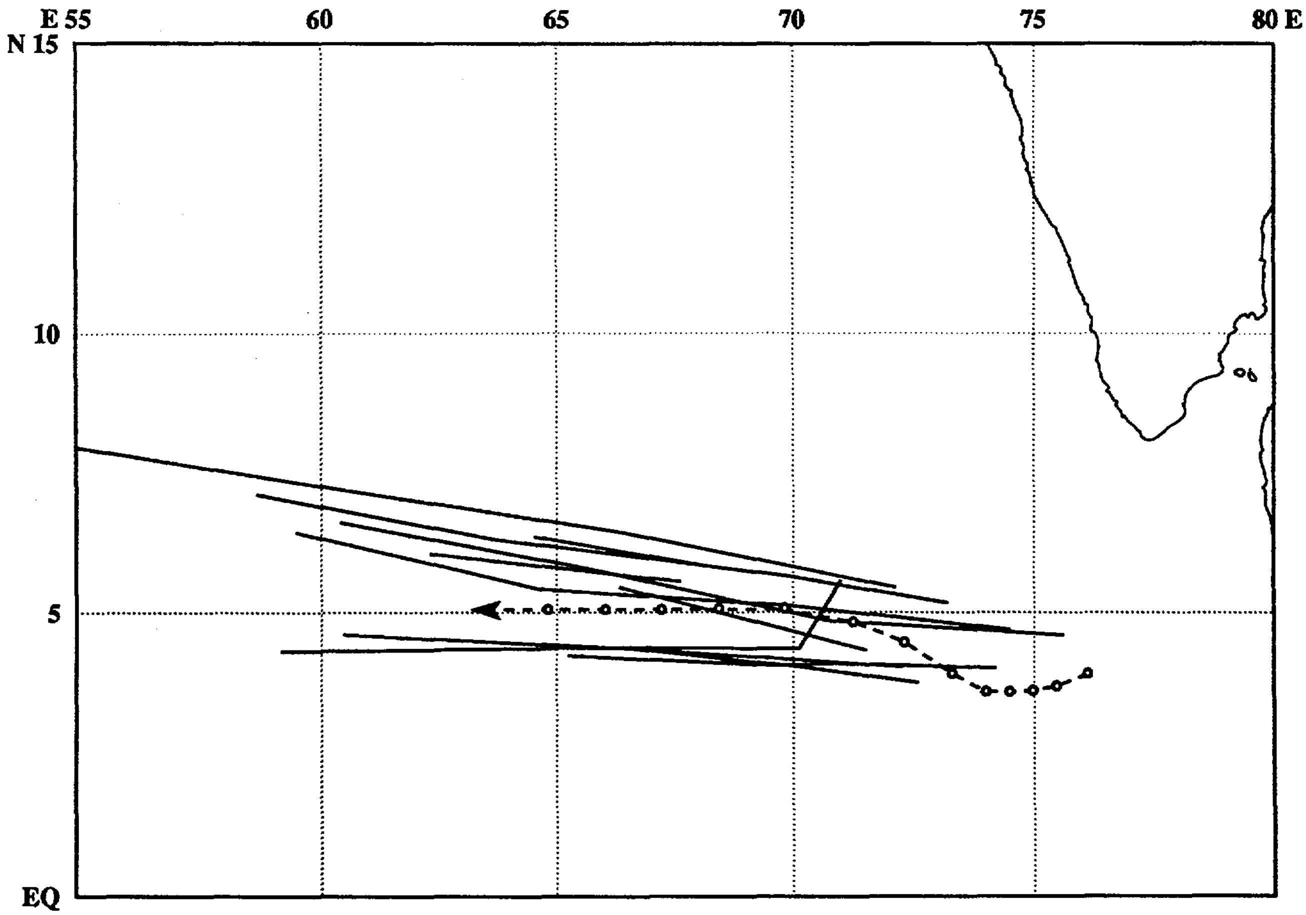
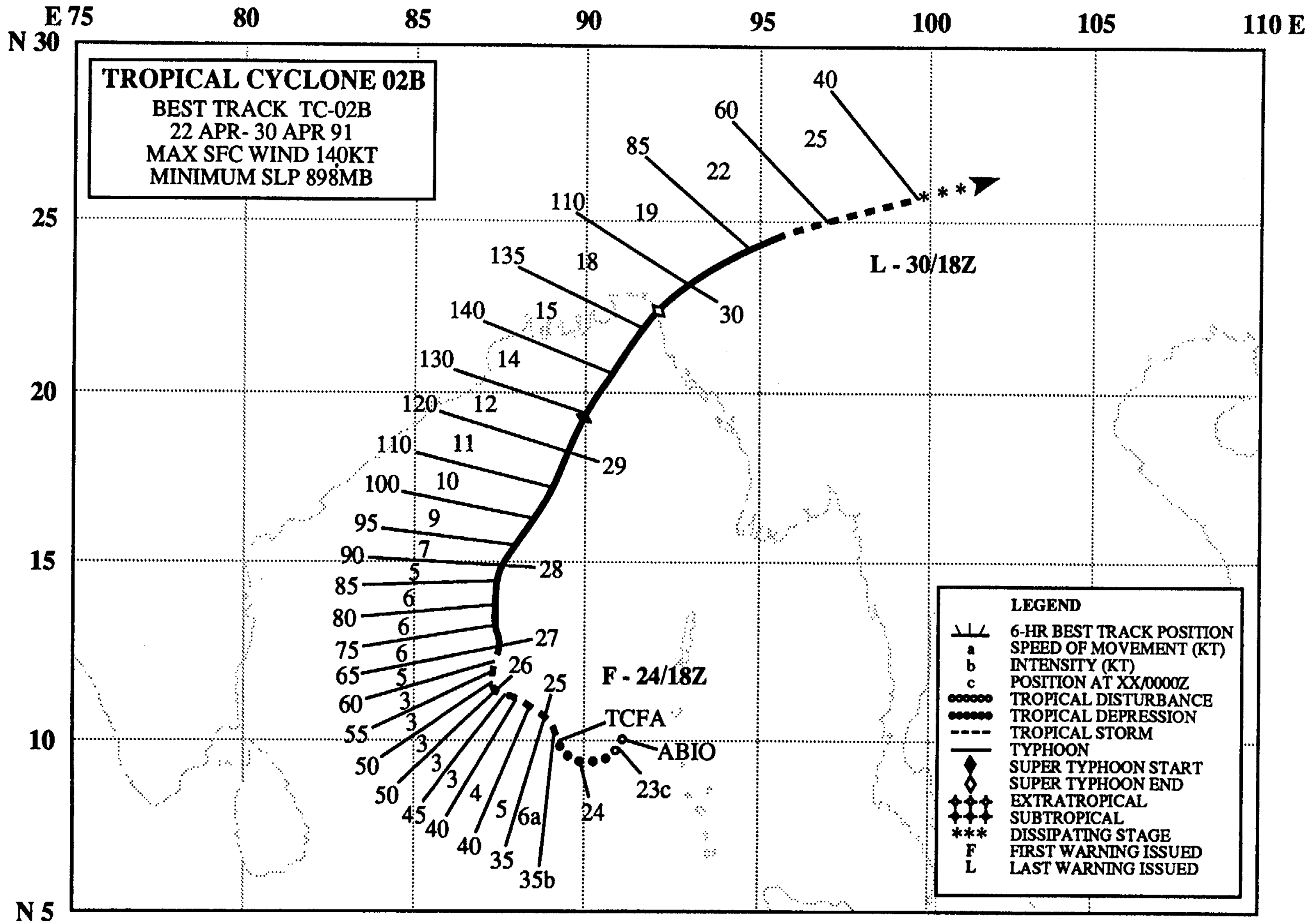


Figure 3-01A-1. On the same day that hostilities erupted in the Persian Gulf, an area of organized convection persisted near Sri Lanka. Because this area posed a potential threat to Allied forces operating in the Arabian Sea, Persian Gulf and the Red Sea, and the 141800Z January Significant Tropical Weather Advisory was reissued at 142300Z. A steady increase in convection which indicated that the disturbance was intensifying, prompted a Tropical Cyclone Formation Alert at 170300Z. The first warning followed at 170600Z. Tropical Cyclone 01A tracked westward under a narrow subtropical ridge, and failed to intensify past minimal tropical storm intensity due to strong vertical wind shear. Strong upper-level winds stripped most of the deep convection away from the center on 18 January, and the remaining low-level circulation slowly dissipated in the Arabian Sea. The final warning was issued at 200600Z.

Although Tropical Cyclone 01A was the first tropical cyclone to develop during January in the Arabian Sea through the past 20 years of record, it was not a significant factor in the Persian Gulf build-up. Because of its low-latitude track and weak intensity, it had little effect on ships steaming to the Middle East. A summary of JTWC forecasts versus the official best track shows the difficulty in positioning the poorly defined cloud system center, producing the large scatter of initial warning positions.


TROPICAL CYCLONE 02B
BEST TRACK TC-02B
22 APR- 30 APR 91
MAX SFC WIND 140KT
MINIMUM SLP 898MB
E 75
80
85
90
95
100
105
110 E
N 30
25
20
15
10
N 5
L - 30/18Z
F - 24/18Z
TCFA
ABIO
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TROPICAL CYCLONE 02B

I. HIGHLIGHTS

Tropical Cyclone 02B was the deadliest and most destructive natural disaster of 1991. It occurred nineteen years after an estimated 300,000 lives were lost in a similar cyclone which struck the low-lying Ganges River delta region of Bangladesh. On April 29 and 30, 1991, Tropical Cyclone 02B (TC 02B) devastated the coastal city of Chittagong (located 115 nm (210 km) southeast of the capital city of Dacca) and the surrounding area with winds in excess of 130 kt (65 m/sec) and a 20-foot (6 m) storm surge. The official death toll was estimated at 138,000, and the damage at US$1.5 billion. The death toll might have been higher than that in 1970, but according to newspaper reports an estimated 2 to 3 million people were evacuated from the coastal region prior to the onset of destructive winds and massive storm surge. A survey of survivors by researchers from the Centers for Disease Control based in Atlanta, Georgia indicated the major reason that many people did not heed the warnings was that they did not believe the cyclone would be as severe as forecast.

II. TRACK AND INTENSITY

On 22 April, westerly winds and persistent cloudiness in the equatorial regions of the North Indian Ocean spawned a large cyclonic circulation which became evident in the synoptic data and satellite imagery over the southern Bay of Bengal. By 24 April, the cloud mass associated with the circulation encompassed nearly the entire Bay of Bengal. Ships reported that surface winds had increased to over 30 kt (15 m/sec). These data prompted the issuance of a Tropical Cyclone Formation Alert at 241400Z. The first warning followed shortly afterward at 241800Z when the tropical cyclone showed signs of rapid development. Steady intensification continued as TC 02B passed through the axis of the subtropical ridge on 27 April and recurved. On 28 April, acceleration started due to the influence of stronger mid-level southwesterlies. The southwesterlies aloft also enhanced upper-level outflow, and TC02B rapidly intensified into a rare Bay of Bengal cyclone of super typhoon intensity (Figure 3-02B-1). At landfall, the center of the eye of TC 02B passed 30 nm (55 km) south of Chittagong at 291900Z. Official reports stated that the destructive fury lasted eight hours in Chittagong. As the tropical cyclone weakened rapidly over the mountainous terrain inland, its torrential rains caused extensive flooding in the region.

III. FORECAST PERFORMANCE

Initial JTWC track forecasts moved TC 02B slowly northwestward toward the east coast of India as the subtropical high over India retreated westward. However, the mid-tropospheric subtropical high located to the east of the system over central Thailand remained fixed and acted as the primary steering mechanism. The cyclone tracked slowly northward between that subtropical high and the high over India. After 271800Z, JTWC anticipated that recurvature would in fact occur, and subsequent warnings indicated that TC 02B would strike the coast of Bangladesh (Figure 3-02B-2). The actual point of landfall near Cittagong on the coast of Bangladesh was correctly forecast after the 281200Z warning, 31 hours prior to landfall .

The first few JTWC forecasts indicated that TC 02B would track slowly northwestward and intensify before making landfall in eastern India. JTWC forecasters anticipated significant development because of the combination of weak vertical wind shear and strong speed divergence aloft, both north and south of the cyclone. On the 280600Z warning, JTWCs predictions indicated the tropical cyclone

would cross the coast of Bangladesh at an intensity of about 100 kt (50 m/sec). Commencing with the warning at 290000Z, JTWC intensity rationale changed as the Center forecast that the maximum sustained surface winds at landfall would exceed 120 kt (60 m/sec) due to anticipated continued rapid intensification.

IV. IMPACT

In terms of storm surge, the Bay of Bengal is the most dangerous tropical cyclone basin in the World. Not only are the physical characteristics of the basin conducive to producing very large storm surges, but the low lying coastal areas are heavily populated. In addition to the tremendous loss of life due to TC02B, ten million people, one-tenth of the population of Bangladesh, were displaced as an estimated one million homes were destroyed. The human suffering associated with this event was staggering.

Communicating by telephone, JTWC kept the U.S. Embassy in Dacca informed of the cyclone's expected track and characteristics for the 48-hour period prior to it hitting land. This communication squelched rumors that the cyclone would strike the Dacca-Ganges delta region of Bangladesh, and probably prevented an unnecessary evacuation of Embassy personnel.

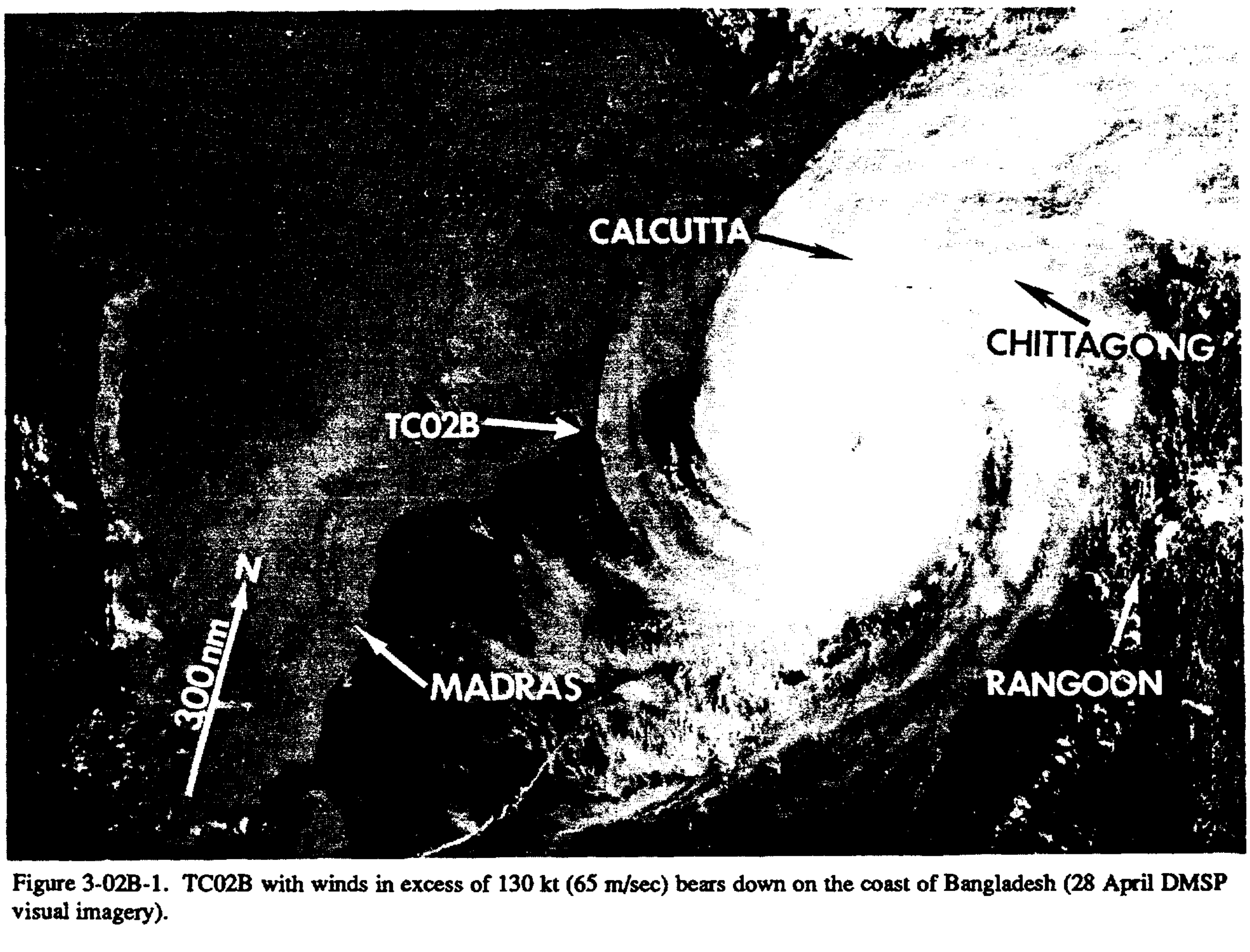


Figure 3-02B-1. TC02B with winds in excess of 130 kt (65 m/sec) bears down on the coast of Bangladesh (28 April DMSP visual imagery).

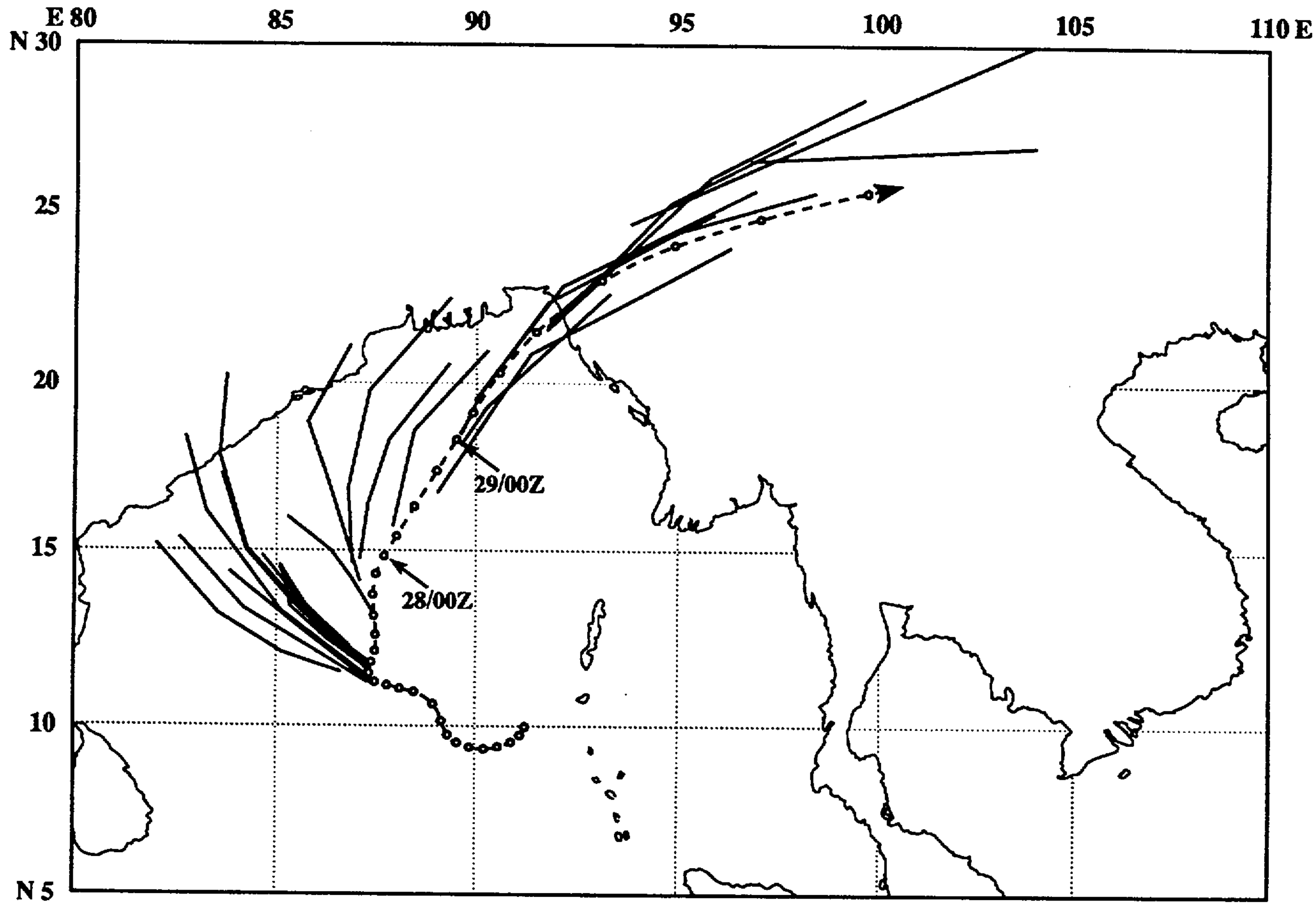
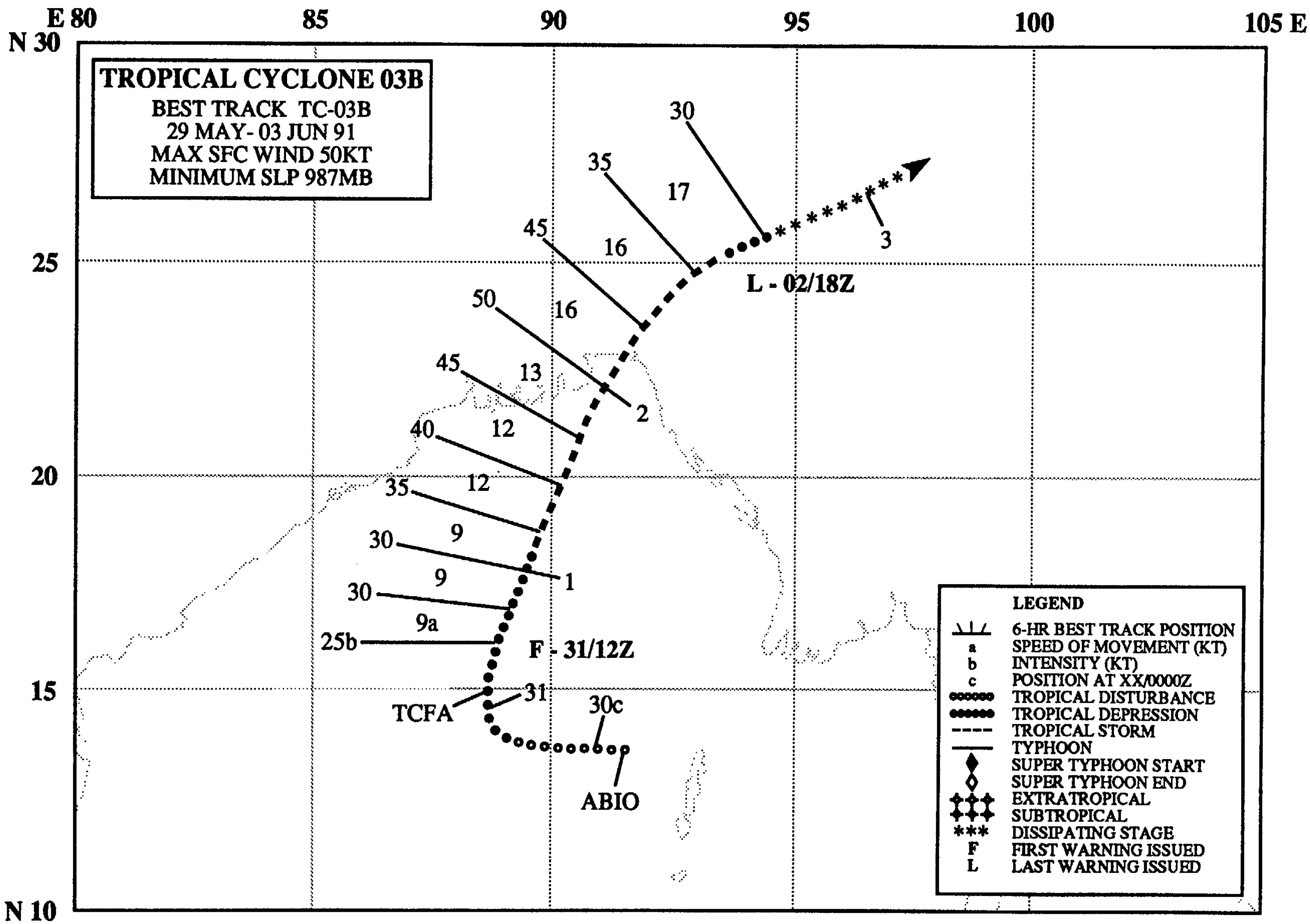


Figure 3-02B-2. Summary of JTWC forecasts (solid lines) for TC02B superimposed on the best track (dashed line).



TROPICAL CYCLONE 03B
BEST TRACK TC-03B
29 MAY- 03 JUN 91
MAX SFC WIND 50KT
MINIMUM SLP 987MB
E 80
85
90
95
100
105 E
N 30
25
20
15
N 10
30
35
17
45
16
50
16
45
13
40
12
35
12
30
9
30
9
25b
9a
3
L - 02/18Z
2
1
F - 31/12Z
TCFA
31
30c
ABIO
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TROPICAL CYCLONE 03B

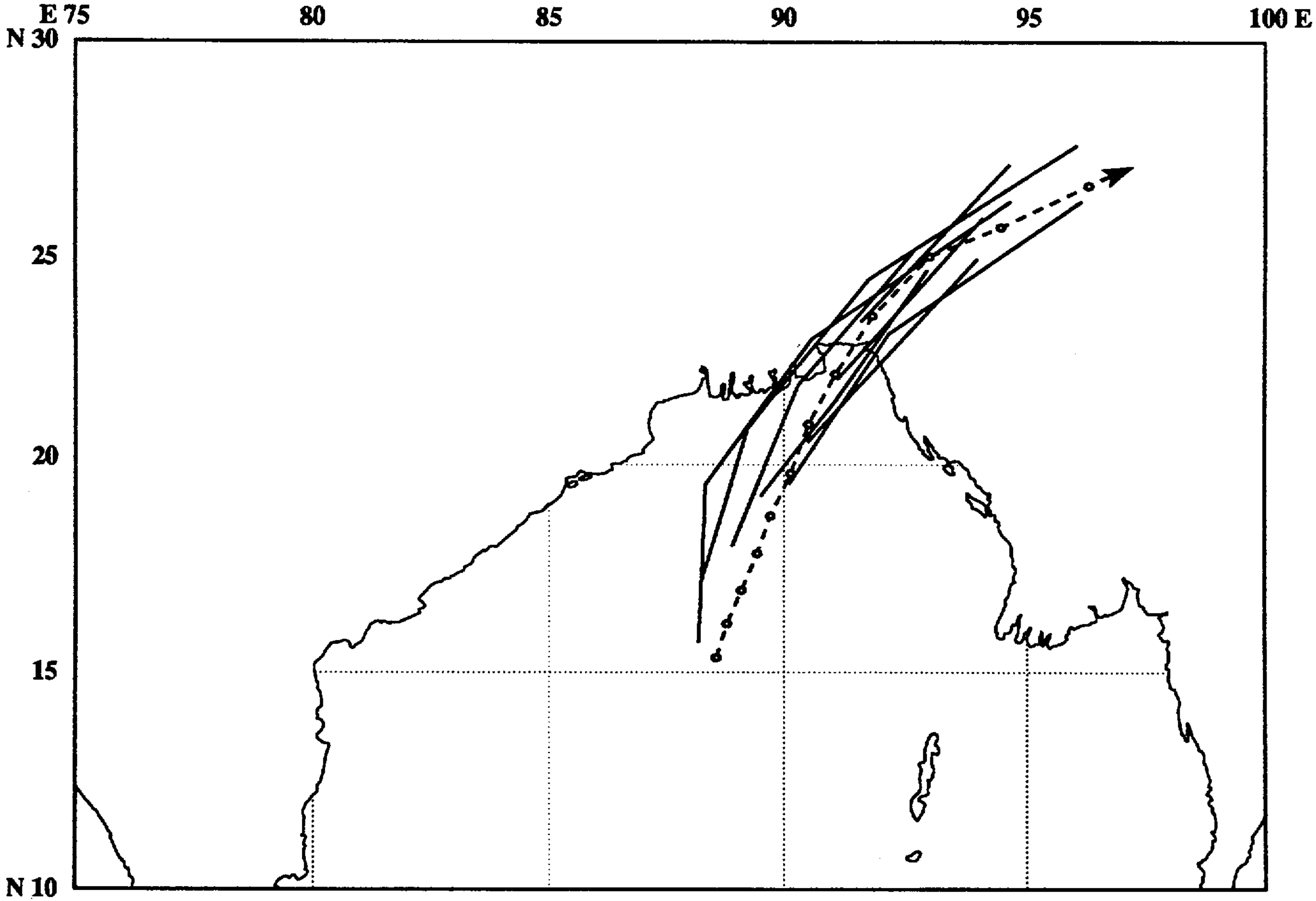
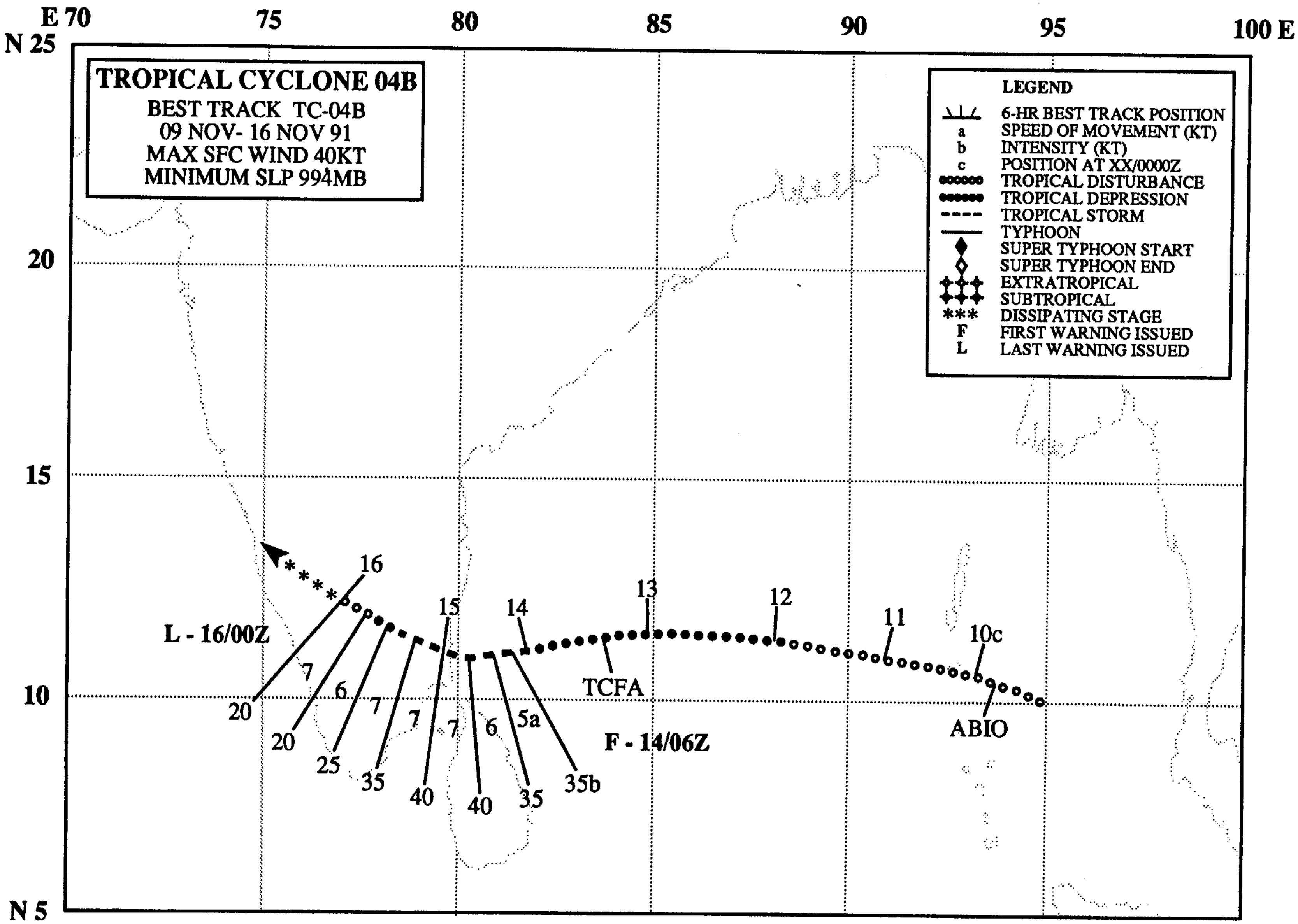


Figure 3-03B-1. In the aftermath of the devastation due to Tropical Cyclone 02B, another destructive weather system, Tropical Cyclone 03B, struck the same coastline of Bangladesh one month later, and caused further damage. Cyclone 03B was initially mentioned on the 291800Z May Significant Tropical Weather Advisory as a weak, poorly organized low-level circulation. Over the next 30 hours, it gradually intensified and tracked westward. As the system began to move northward and gain convective organization, a Tropical Cyclone Formation Alert was issued at 310030Z followed by the first warning at 311200Z. Tropical Cyclone 03B reached its peak intensity of 50 kt (25 m/sec) shortly before landfall, midway between Dacca and Chittagong on the coast of Bangladesh at 020400Z, after which it rapidly dissipated over mountainous terrain inland. The final warning was issued at 021800Z.

The cyclone caused minor flooding in Bangladesh and disrupted the relief efforts of Operation SEA ANGEL by forcing the amphibious cargo ship, **USS St. Louis,** to seek room to maneuver offshore. Tropical Cyclone 03B's impact on SEA ANGEL was minimized by accurate track and intensity forecasts, and by up-to-the-minute information provided to decision makers by JTWC forecasters. A comparison of JTWC forecasts to the final best track is provided.


TROPICAL CYCLONE 04B
BEST TRACK TC-04B
09 NOV- 16 NOV 91
MAX SFC WIND 40KT
MINIMUM SLP 994MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 70
75
80
85
90
95
100 E
N 25
20
15
10
N 5
L - 16/00Z
F - 14/06Z
TCFA
ABIO
16
15
14
13
12
11
10c
20
20
25
35
40
40
35
35b
7
6
7
7
7
6
5a

TROPICAL CYCLONE 04B

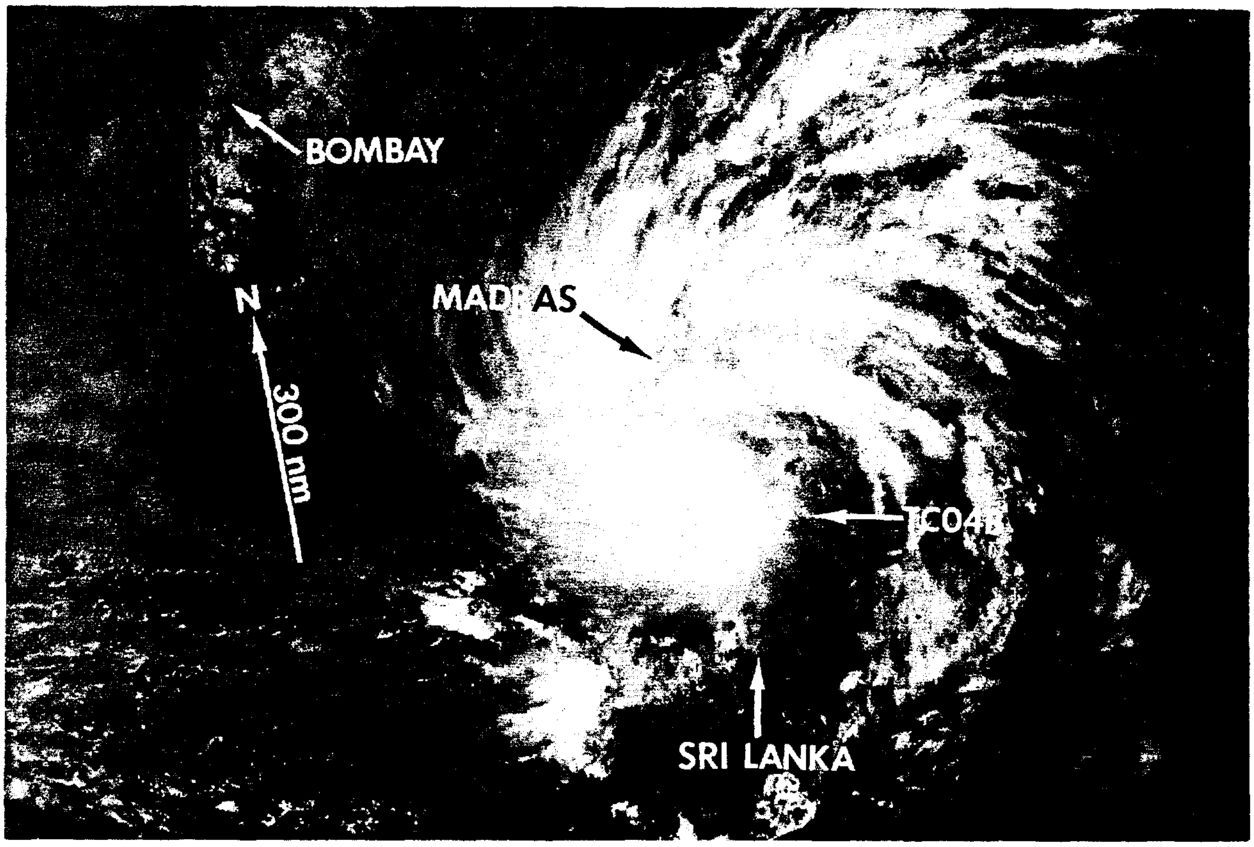


Figure 3-04B-1 Tropical Cyclone 04B makes landfall on the southern coast of India at maximum intensity (140305Z November DMSP visual imagery).

Tropical Cyclone 04B was the only cyclone to develop in the North Indian Ocean during the fall transition season. After being initially detected on 9 November, the disturbance was mentioned on the 1800Z Significant Tropical Weather Advisory. It tracked westward in the Bay of Bengal for the next three days without a significant increase in organization. At 131800Z, a Tropical Cyclone Formation Alert was issued when 131200Z synoptic data revealed a well-developed upper-level anticyclone had developed over the broad low-level circulation center. Twelve hours later, the first warning on Tropical Cyclone 04B indicated that while the system was rapidly approaching the southern coast of India, it was expected to maintain sufficient organization after crossing the Indian peninsula to allow it to reintensify in the Arabian Sea. For this reason, JTWC continued to issue warnings while the cyclone was over land. After reaching its maximum intensity of 40 kt (21 m/sec) just prior to landfall, the system crossed the Indian coast near Nagappattinam approximately 140 nm (260 km) south of Madras at 142300Z. It did not reintensify in the Arabian Sea, and the final warning was issued at 160000Z.

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4. SUMMARY OF SOUTH PACIFIC AND SOUTH INDIAN OCEAN TROPICAL CYCLONES

4.1 GENERAL

On 1 October 1980, JTWC's area of responsibility (AOR) was expanded to include the Southern Hemisphere from 180° east longitude westward to the coast of Africa. Details on Southern Hemisphere tropical cyclones and JTWC warnings from July 1980 through June 1982 are contained in Diercks et al. (1982) and from July 1982 through June 1984, in Wirfel and Sandgathe (1986). Information on Southern Hemisphere tropical cyclones after June 1984 can be found in the applicable Annual Tropical Cyclone Report.

The Naval Western Oceanography Center (NWOC) Pearl Harbor, HI issues warnings on tropical cyclones in the South Pacific east of 180° east longitude.

In accordance with CINCPACINST 3140.1U (series), Southern Hemisphere tropical cyclones are numbered sequentially from 1 July through 30 June. This convention is established to encompass the Southern Hemisphere tropical cyclone season, which primarily occurs from January through April. There are two ocean basins for warning purposes - the South Indian (west of 135° east longitude) and the South Pacific (east of 135° east longitude) - which are identified by appending the suffixes "S" and "P" respectively to the tropical cyclone number.

Intensity estimates for Southern Hemisphere tropical cyclones are derived from the interpretation of satellite imagery using the Dvorak technique (Dvorak, 1984) and in rare instances from surface observations. The Dvorak technique relates specific cloud signatures to maximum sustained one-minute average wind speeds. The conversion from maximum sustained winds to minimum sea-level pressure is obtained from the Atkinson and Holliday (1977) relationship (Table 4-1).

4.2. SOUTH PACIFIC AND SOUTH INDIAN OCEAN TROPIAL CYCLONES

Tropical cyclone activity in 1991 (Table 4-2) was below the climatological mean of 27 storms, and the second lowest seasonal total since 1981 (Table 4-3). The below-average number of cyclones was a reflection of light activity in the South Pacific. Although the number of storms in the rest of the Southern Hemisphere was near normal, only one tropical

TABLE 4-1 **MAXIMUM SUSTAINED SURFACE WINDS AND EQUIVALENT MINIMUM SEA-LEVEL PRESSURE (ATKINSON AND HOLLIDAY, 1977)**

MAXIMUM SUSTAINED SURFACE WIND (KT)	MINIMUM SEA-LEVEL PRESSURE (MB)
30	1000
35	997
40	994
45	991
50	987
55	984
60	980
65	976
70	972
75	967
80	963
85	958
90	954
95	948
100	943
105	938
110	933
115	927
120	922
125	916
130	910
135	906
140	898
145	892
150	885
155	879
160	872
165	865
170	858
175	851
180	844

cyclone, Sina (03P) occurred east of 165°E (Table 4-4). Tropical cyclone activity was spread evenly throughout the season, which began in late September and ended in early June. Peak activity occurred on 27 February, when four cyclones were in warning status at the same time.

Twenty-six initial tropical cyclone formation alerts were issued in 1991, and except for Tropical Cyclone 10S, each preceded the first warning. The JTWC was in warning status a total of 105 days, which includes 20 days when the JTWC issued warnings on two or more Southern Hemisphere cyclones. Tropical Cyclone 08S (Bella), which lasted for 15 days, was the only system to reach super typhoon intensity.

TABLE 4-2

SOUTH PACIFIC AND SOUTH INDIAN OCEAN
1990 SIGNIFICANT TROPICAL CYCLONES
(1 July 1990 - 30 June 1991)

TROPICAL CYCLONE	PERIOD OF WARNING	NUMBER WARNINGS ISSUED	MAXIMUM SURFACE WINDS-KT (M/SEC)	ESTIMATED MSLP (MB)
01S ----	21 Sep - 25 Sep	10	30(15)	1000
02S ----	18 Oct - 20 Oct	5	30(15)	1000
03P Sina**	24 Nov - 29 Nov	8	125(64)	916
04S ----	03 Dec - 04 Dec	3	55(28)	984
05S Laurence	15 Dec - 16 Dec	4	35(18)	997
06P Joy	18 Dec - 26 Dec	16	90(46)	954
07S Alison	12 Jan - 18 Jan	18	65(33)	976
08S Bella	20 Jan - 04 Feb	31	130(67)	910
09S Chris	16 Feb - 21 Feb	11	50(26)	987
09S Chris*	22 Feb - 23 Feb	3	30(15)	1000
10S Cynthia	16 Feb - 17 Feb	3	50(26)	987
11S Daphne	22 Feb - 27 Feb	12	60(31)	980
12S Debra	24 Feb - 04 Mar	17	90(46)	954
13P Kelvin	25 Feb - 06 Mar	19	55(28)	984
14S Elma	27 Feb - 03 Mar	10	60(31)	980
15P ----	06 Mar - 07 Mar	2	30(15)	1000
16P ----	18 Mar - 20 Mar	5	30(15)	1000
17S Fatima	22 Mar - 01 Apr	21	90(46)	954
18S Errol	25 Mar - 29 Mar	15	110(57)	933
18S Errol*	30 Mar - 31 Mar	4	35(18)	997
19S Marian	10 Apr - 19 Apr	18	95(49)	948
20S Fifi	16 Apr - 20 Apr	9	55(28)	984
21P Lisa	07 May - 12 May	11	70(36)	972
22S Gritelle	08 Jun - 12 Jun	9	40(21)	994
	Total:	**264**		

* Regenerated

** An Additional 3 Warnings Issued by NWOC

NOTE: Names of Southern Hemisphere Tropical Cyclones are given by the Regional Warning Centers (Nadi, Brisbane, Darwin, Perth, Reunion and Mauritius) and are appended to JTWC Warnings, when available.

TABLE 4-3 **MONTHLY DISTRIBUTION OF SOUTH PACIFIC AND SOUTH INDIAN OCEAN TROPICAL CYCLONES**

YEAR	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	TOTAL
(1959-1978) AVERAGE*	-	-	-	0.4	1.5	3.6	6.1	5.8	4.7	2.1	0.5	-	24.7
1981	0	0	0	1	3	2	6	5	3	3	1	0	24
1982	1	0	0	1	1	3	9	4	2	3	1	0	25
1983	1	0	0	1	1	3	5	6	3	5	0	0	25
1984	1	0	0	1	2	5	5	10	4	2	0	0	30
1985	0	0	0	0	1	7	9	9	6	3	0	0	35
1986	0	0	1	0	1	1	9	9	6	4	2	0	33
1987	0	1	0	0	1	3	6	8	3	4	1	1	28
1988	0	0	0	0	2	3	5	5	3	1	2	0	21
1989	0	0	0	0	2	1	5	8	6	4	2	0	28
1990	2	0	1	1	2	2	4	4	10	2	1	0	29
1991	0	0	1	1	1	3	2	5	5	2	1	1	22
TOTAL CASES:	5	1	3	6	17	33	65	73	51	33	11	2	300
(1981-1991) AVERAGE:	0.5	0.1	0.3	0.5	1.5	3.0	5.9	6.6	4.6	3.0	1.0	0.1	27.3

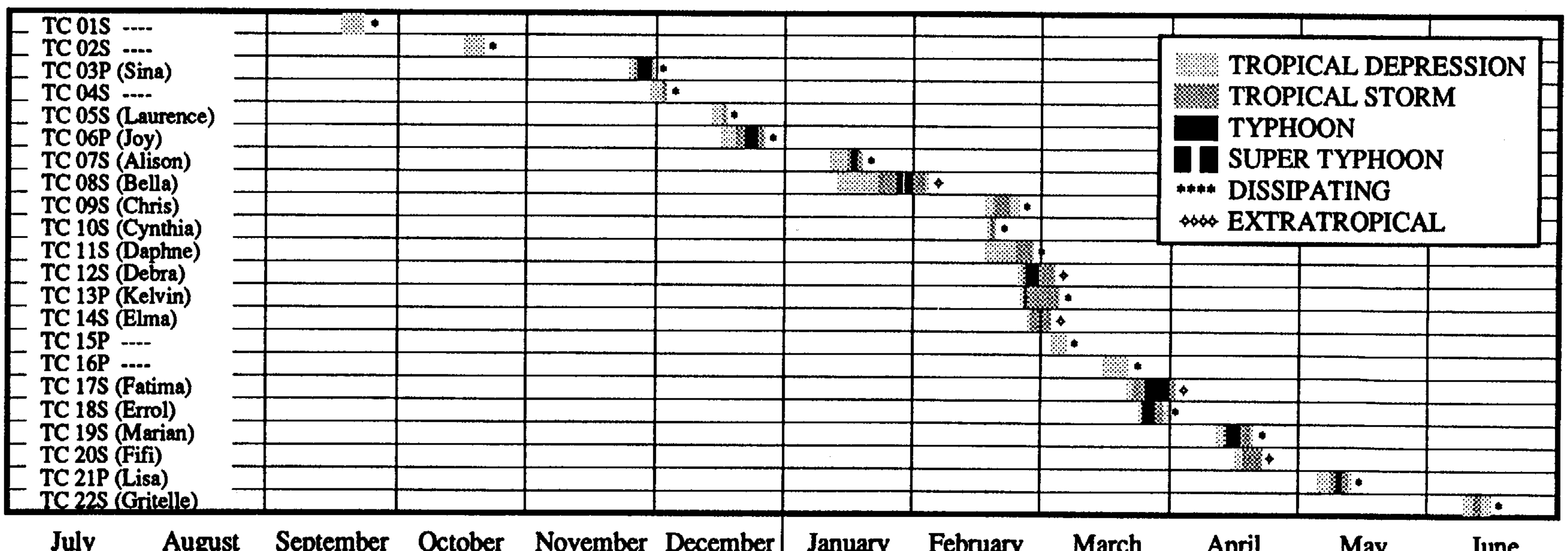
* (Gray, 1979)

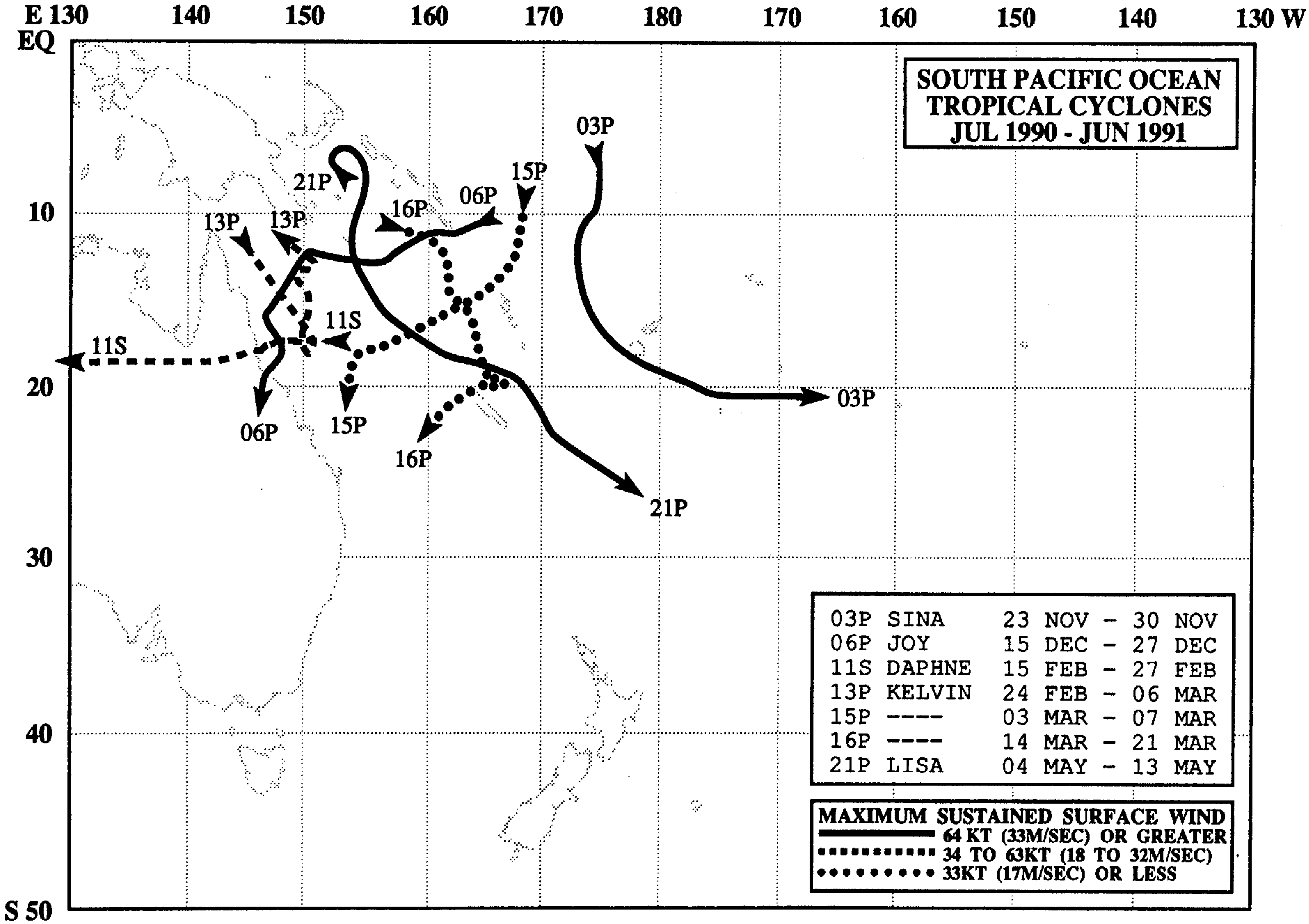
TABLE 4-4 **ANNUAL VARIATION OF SOUTHERN HEMISPHERE TROPICAL CYCLONES BY OCEAN BASIN**

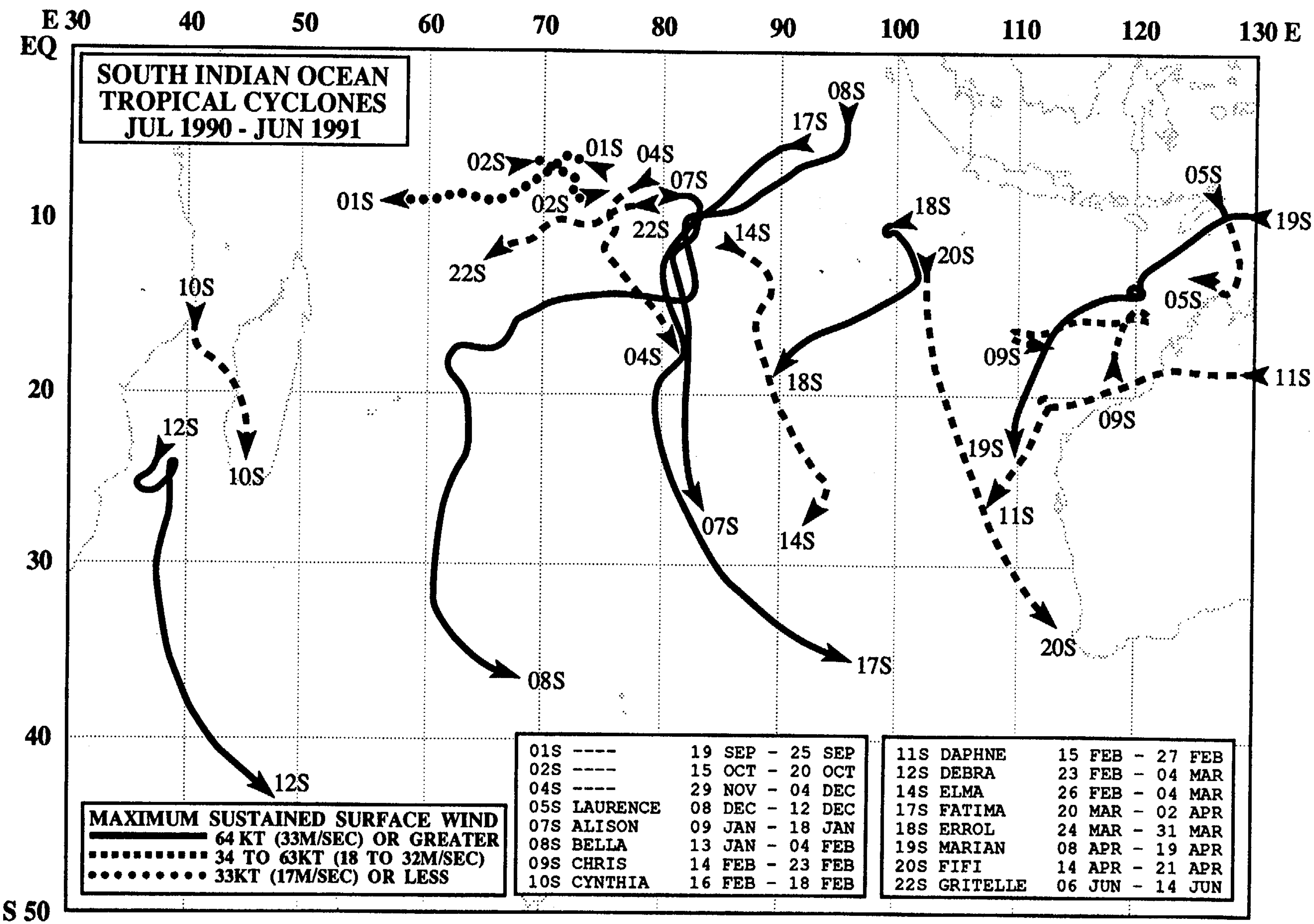
YEAR	SOUTH INDIAN (WEST OF 105°E)	AUSTRALIAN (105°E - 165°E)	SOUTH PACIFIC (EAST OF 165°E)	TOTAL
(1959-1978) AVERAGE*	8.4	10.3	5.9	24.7
1981	13	8	3	24
1982	12	11	2	25
1983	7	6	12	25
1984	14	14	2	30
1985	14	15	6	35
1986	14	16	3	33
1987	9	8	11	28
1988	14	2	5	21
1989	12	9	7	28
1990	18	8	3	29
1991	11	10	1	22
TOTAL CASES:	138	107	55	300
(1981-1991) AVERAGE:	12.5	9.7	5.0	27.3

* (Gray, 1979)

Figure 4-1. Chronology of South Pacific and South Indian Ocean tropical cyclones for 1990.




SOUTH PACIFIC OCEAN
TROPICAL CYCLONES
JUL 1990 - JUN 1991
E 130
140
150
160
170
180
170
160
150
140
130 W
EQ
10
20
30
40
S 50
03P
15P
06P
16P
21P
13P
13P
11S
11S
06P
15P
16P
21P
03P
03P SINA 23 NOV - 30 NOV
06P JOY 15 DEC - 27 DEC
11S DAPHNE 15 FEB - 27 FEB
13P KELVIN 24 FEB - 06 MAR
15P ---- 03 MAR - 07 MAR
16P ---- 14 MAR - 21 MAR
21P LISA 04 MAY - 13 MAY
MAXIMUM SUSTAINED SURFACE WIND
64 KT (33M/SEC) OR GREATER
34 TO 63KT (18 TO 32M/SEC)
33KT (17M/SEC) OR LESS


SOUTH INDIAN OCEAN
TROPICAL CYCLONES
JUL 1990 - JUN 1991
E 30
40
50
60
70
80
90
100
110
120
130 E
EQ
10
20
30
40
S 50
MAXIMUM SUSTAINED SURFACE WIND
64 KT (33M/SEC) OR GREATER
34 TO 63KT (18 TO 32M/SEC)
33KT (17M/SEC) OR LESS
01S ---- 19 SEP - 25 SEP
02S ---- 15 OCT - 20 OCT
04S ---- 29 NOV - 04 DEC
05S LAURENCE 08 DEC - 12 DEC
07S ALISON 09 JAN - 18 JAN
08S BELLA 13 JAN - 04 FEB
09S CHRIS 14 FEB - 23 FEB
10S CYNTHIA 16 FEB - 18 FEB
11S DAPHNE 15 FEB - 27 FEB
12S DEBRA 23 FEB - 04 MAR
14S ELMA 26 FEB - 04 MAR
17S FATIMA 20 MAR - 02 APR
18S ERROL 24 MAR - 31 MAR
19S MARIAN 08 APR - 19 APR
20S FIFI 14 APR - 21 APR
22S GRITELLE 06 JUN - 14 JUN

5. SUMMARY OF FORECAST VERIFICATION

5.1 ANNUAL FORECAST VERIFICATION

Verification of warning positions and intensities at initial, 24-, 48- and 72-hour forecast periods was made against the final best track. The (scalar) track forecast, along-track and cross-track errors (illustrated in Figure 5-1) were calculated for each verifying JTWC forecast. These data, in addition to a detailed summary for each tropical cyclone, is included as Chapter 6 (formerly Annex A). This section summarizes verification data for 1991 and contrasts it with annual verification statistics from previous years.

5.1.1 NORTH WEST PACIFIC OCEAN — The frequency distributions of errors for warning positions and 24-, 48- and 72-hour forecasts are presented in Figures 5-2A through 5-2D, respectively. Table 5-1 includes mean track, along-track and cross-track errors for 1978-1991. Figure 5-3 shows mean track errors and a 5-year moving average of track errors at 24-, 48- and 72-hours for the past 22 years. Table 5-2 lists annual mean track errors from 1959, when the JTWC was founded, until the present. Figure 5-4 illustrates JTWC intensity forecast errors at 24-, 48- and 72-hours for the past 22 years.

5.1.2 NORTH INDIAN OCEAN — The frequency distributions of errors for warning positions and 24-, 48- and 72-hour forecasts are presented in Figures 5-5A through 5-5D, respectively. Table 5-3 includes mean track, along-track and cross-track errors for 1971-1991. Figure 5-6 shows mean track errors and a 5-year moving average of track errors at 24-, 48- and 72-hours for the 21 years that the JTWC has issued warnings in the region.

5.1.3 SOUTH PACIFIC AND SOUTH INDIAN OCEANS — The frequency distributions of errors for warning positions and 24- and 48-hour forecasts are presented in Figures 5-7A through 5-7C, respectively. Table 5-4 includes mean track, along-track and cross-track errors for 1981-1991. Figures 5-8 shows mean track errors and a 5-year moving average of track errors at 24- and 48-hours for the 11 years that the JTWC has issued warnings in the region.

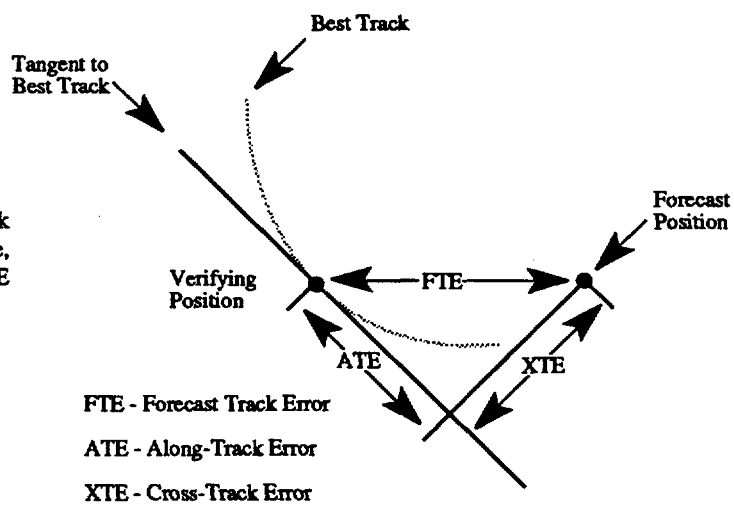


Figure 5-1. Definition of cross-track error (XTE), along-track error (ATE) and forecast track error (FTE). In this example, the XTE is positive (to the right of the best track) and the ATE is negative (behind or slower than the best track).

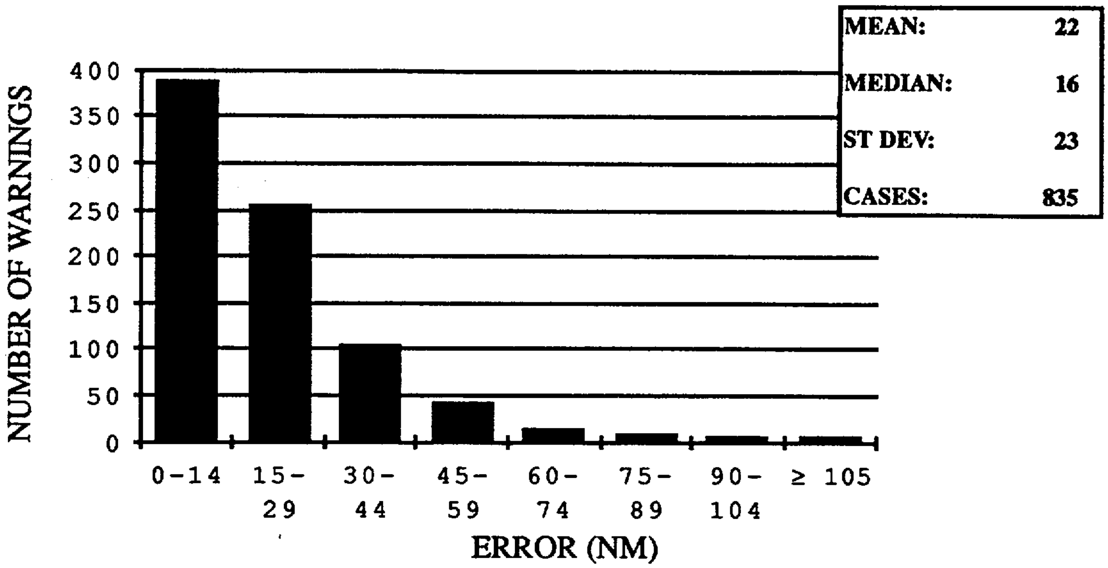


Figure 5-2A. Frequency distribution of initial position errors (15 nm increments) for the Northwest Pacific in 1991. The largest error during 1991 was 231 nm (Tropical Storm Luke (20W)).

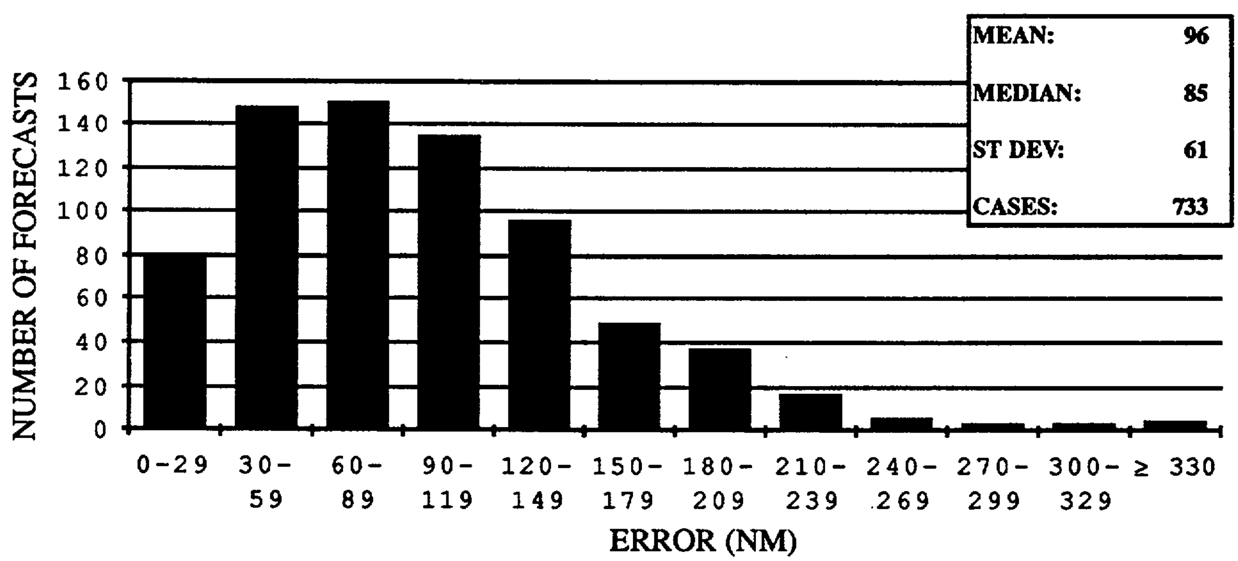


Figure 5-2B. Frequency distribution of 24-hour forecast errors (30 nm increments) for the Northwest Pacific in 1991. The largest error during 1991 was 403 nm (Tropical Storm Luke (20W)).

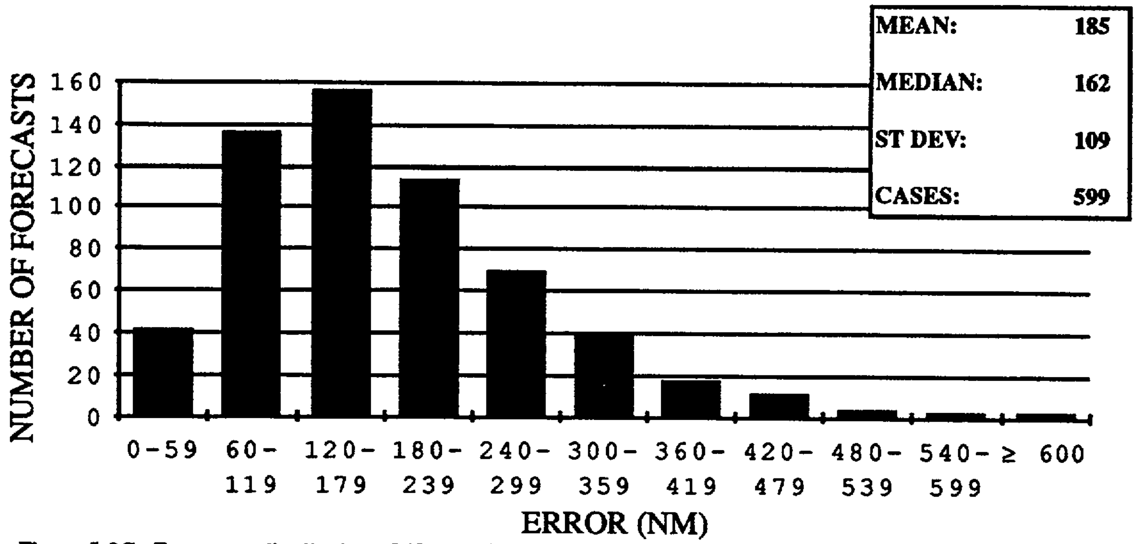


Figure 5-2C. Frequency distribution of 48-hour forecast errors (60 nm increments) for the Northwest Pacific in 1991. The largest error during 1991 was 860 nm (Tropical Storm Luke (20W)).

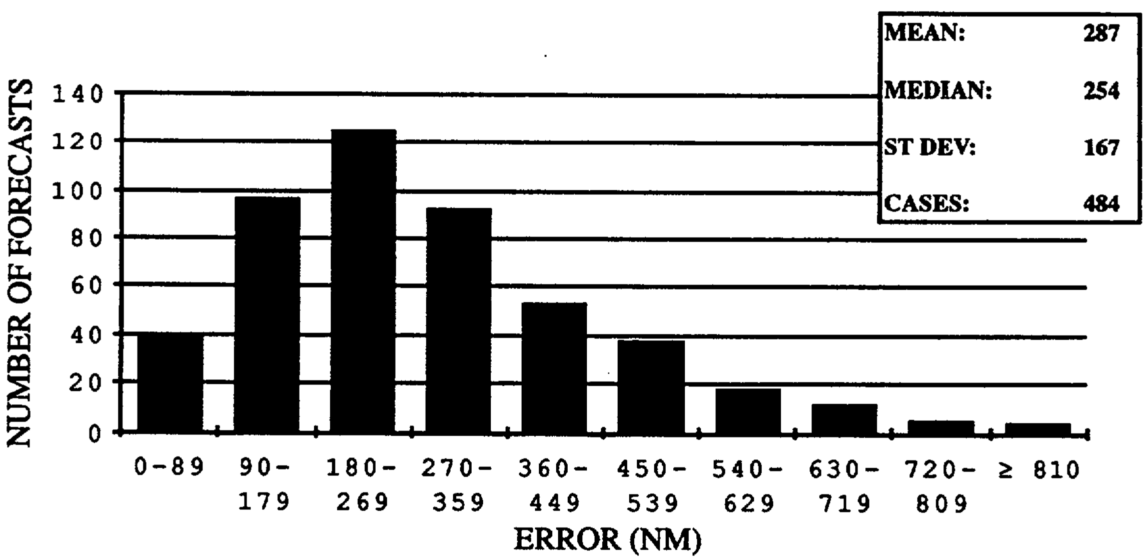


Figure 5-2D. Frequency distribution of 72-hour forecast errors (90 nm increments) for the Northwest Pacific in 1991. The largest error during 1991 was 912 nm (Super Typhoon Ruth (25W)).

TABLE 5-1. JTWC ANNUAL INITIAL POSITION AND FORECAST POSITION ERRORS (NM) 1978-1991 FOR THE NORTHWEST PACIFIC OCEAN

YEAR	NUMBER OF WARNINGS	INITIAL POSITION	NUMBER OF FORECASTS	24-HOUR TRACK	24-HOUR ALONG	24-HOUR CROSS	NUMBER OF FORECASTS	48-HOUR TRACK	48-HOUR ALONG	48-HOUR CROSS	NUMBER OF FORECASTS	72-HOUR TRACK	72-HOUR ALONG	72-HOUR CROSS
1978	696	21	556	126	87	71	420	274	194	151	295	411	296	218
1979	695	25	589	125	81	76	469	227	146	138	366	316	214	182
1980	590	28	491	127	86	76	369	244	165	147	267	391	266	230
1981	584	25	466	124	80	77	348	221	146	131	246	334	206	219
1972	786	19	666	113	74	70	532	238	162	142	425	342	223	211
1983	445	16	342	117	76	73	253	260	169	164	184	407	259	263
1984	611	22	492	117	84	64	378	232	163	131	286	363	238	216
1985	592	18	477	117	80	68	336	231	153	138	241	367	230	227
1986	743	21	645	126	85	70	535	261	183	151	412	394	276	227
1987	657	18	563	107	71	64	465	204	134	127	389	303	198	186
1988	465	23	373	114	85	58	262	216	170	103	183	315	244	159
1989	710	20	625	120	83	69	481	231	162	127	363	350	265	177
1990	794	21	658	120	81	70	404	237	162	138	305	355	242	211
1991	835	22	733	96	69	53	599	185	137	97	484	287	229	146
AVERAGE 78-91:	657	21	548	116	79	68	427	229	159	131	327	347	240	200

NOTE: Cross-track and along-track errors were adopted by the JTWC in 1986. Right-angle errors (used prior to 1986) were re-computed as cross-track and along-track errors after the fact to extend the data base. See Figure 5-1 for the definitions of cross-track and along-track errors.

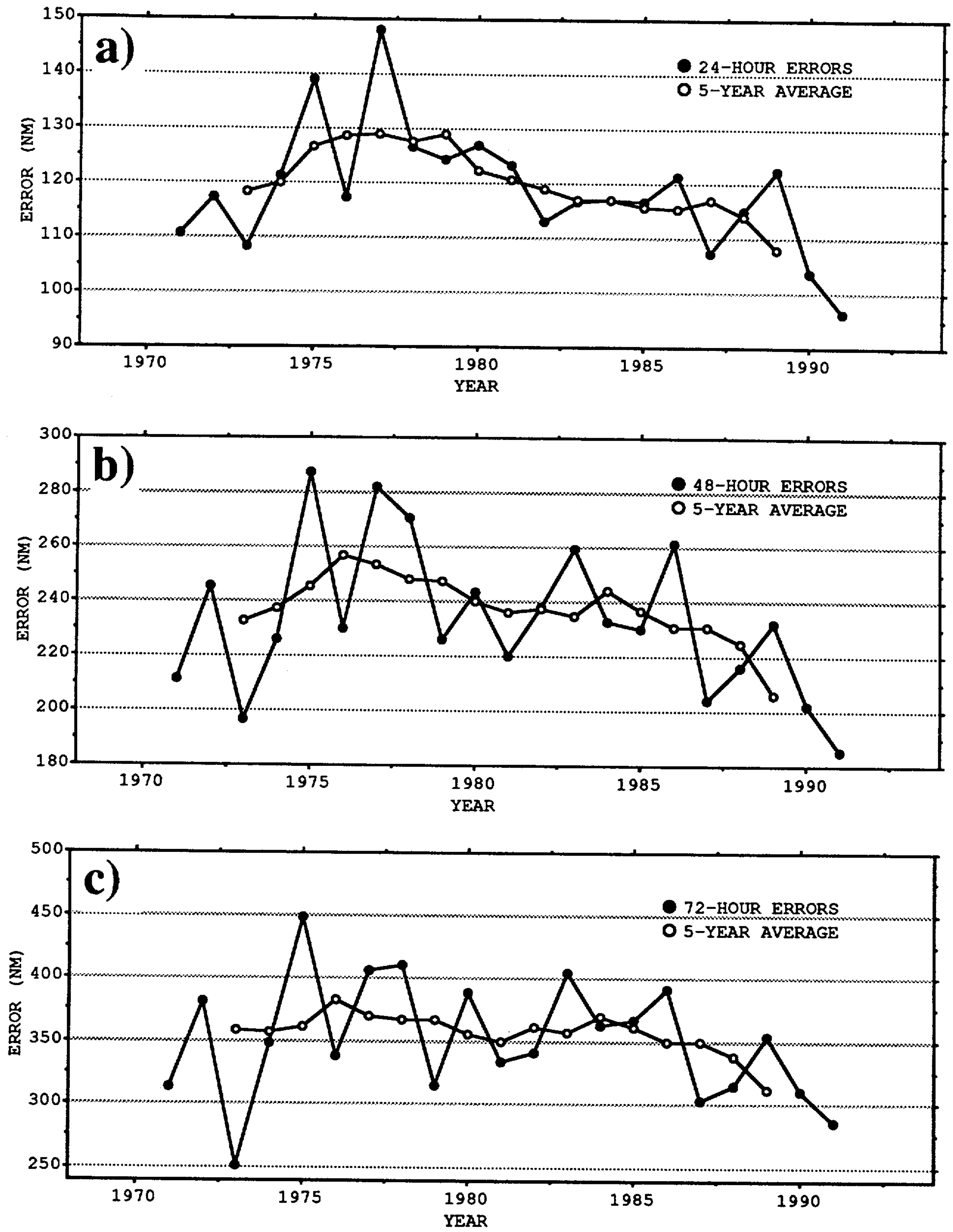


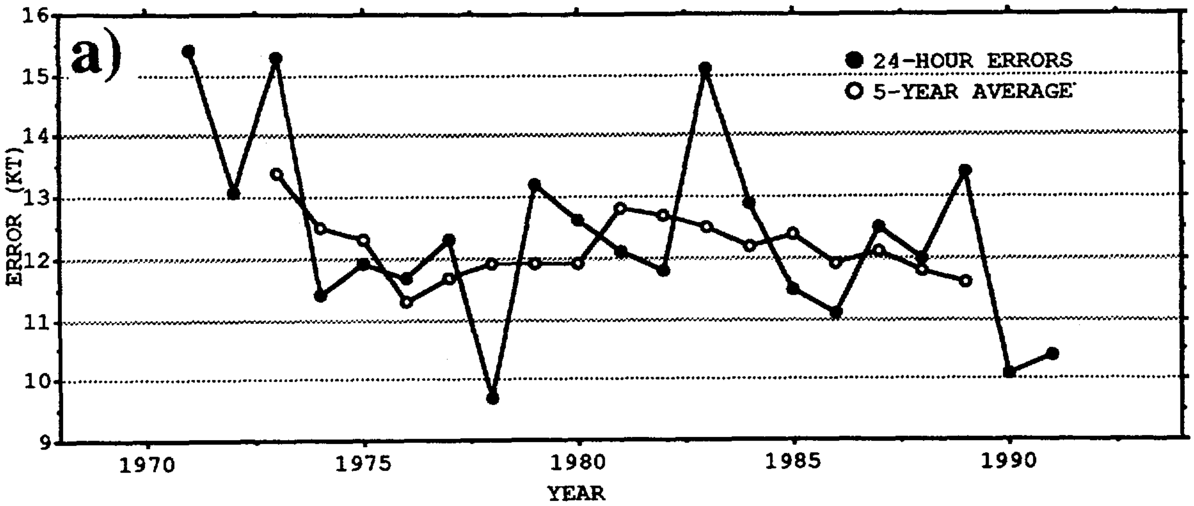
Figure 5-3. Annual mean track forecast errors (nm) and 5-year running mean for a) 24-hours, b) 48-hours and c) 72-hours in the Northwest Pacific Ocean.

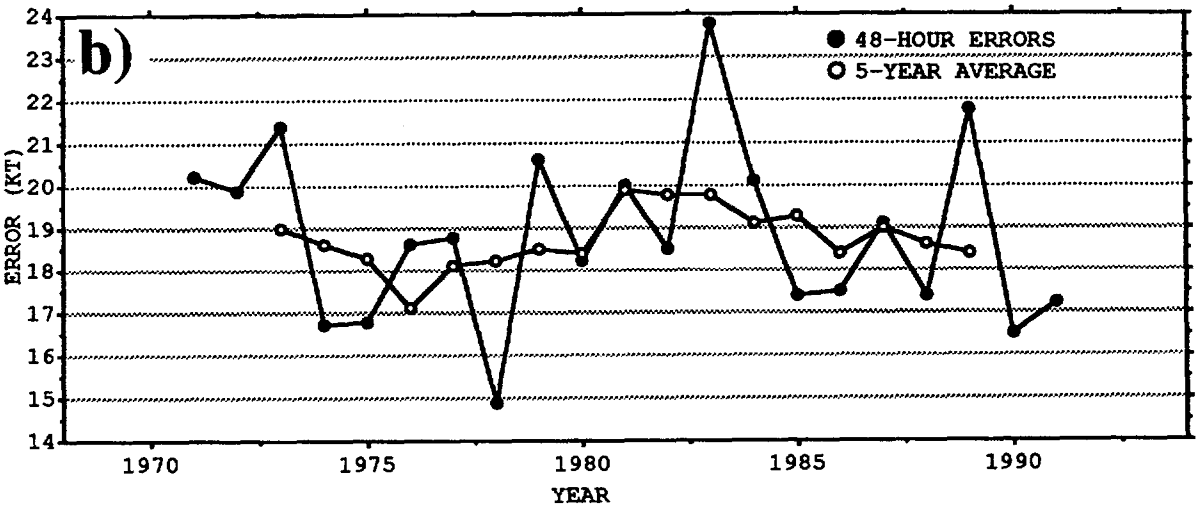
TABLE 5-2 **ANNUAL MEAN FORECAST ERRORS (NM)**
NORTHWEST PACIFIC OCEAN

	24-HOUR		48-HOUR		72-HOUR	
YEAR	ALL /	TYPHOONS*	ALL /	TYPHOONS*	ALL /	TYPHOONS*
1959		117**		267**		
1960		177**		354**		
1961		136		274		
1962		144		287		476
1963		127		246		374
1964		133		284		429
1965		151		303		418
1966		136		280		432
1967		125		276		414
1968		105		229		337
1969		111		237		349
1970	104	98	190	181	279	272
1971	111	99	212	203	317	308
1972	117	116	245	245	381	382
1973	108	102	197	193	253	245
1974	120	114	226	218	348	357
1975	138	129	288	279	450	442
1976	117	117	230	232	338	336
1977	148	140	283	266	407	390
1978	127	120	271	241	410	459
1979	124	113	226	219	316	319
1980	126	116	243	221	389	362
1981	123	117	220	215	334	342
1982	113	114	237	229	341	337
1983	117	110	259	247	405	384
1984	117	110	233	228	363	361
1985	117	112	231	228	367	355
1986	121	117	261	261	394	403
1987	107	101	204	211	303	318
1988	114	107	216	222	315	327
1989	120	107	231	214	350	325
1990	103	98	203	191	310	299
1991	96	93	185	187	286	298

* Forecasts were verified when the tropical cyclone intensities were at least 35 kt (18 m/sec).

** Forecast positions north of 35° north latitude were not verified.





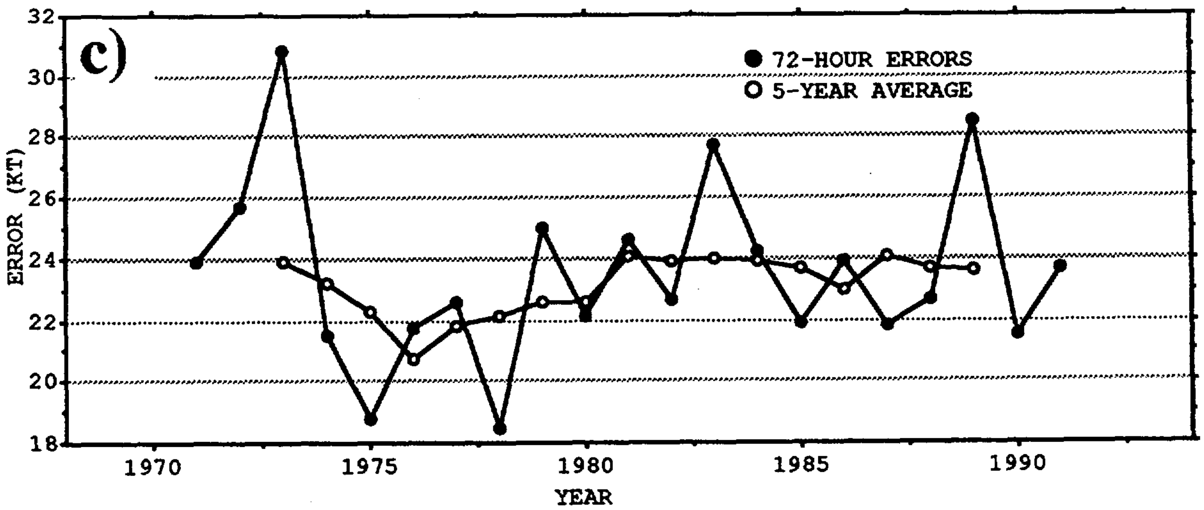
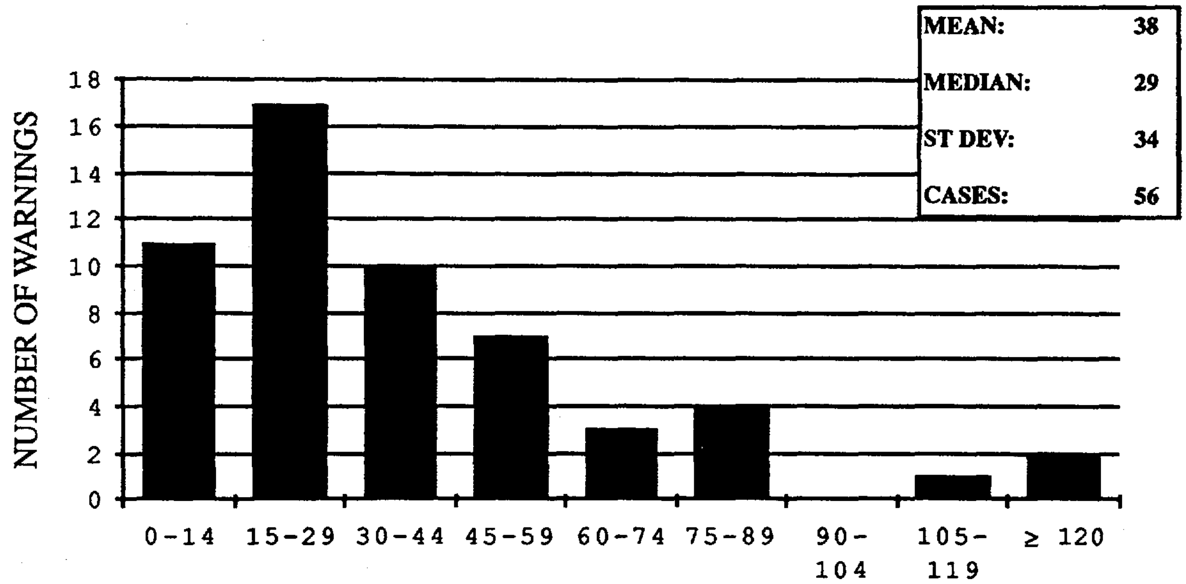
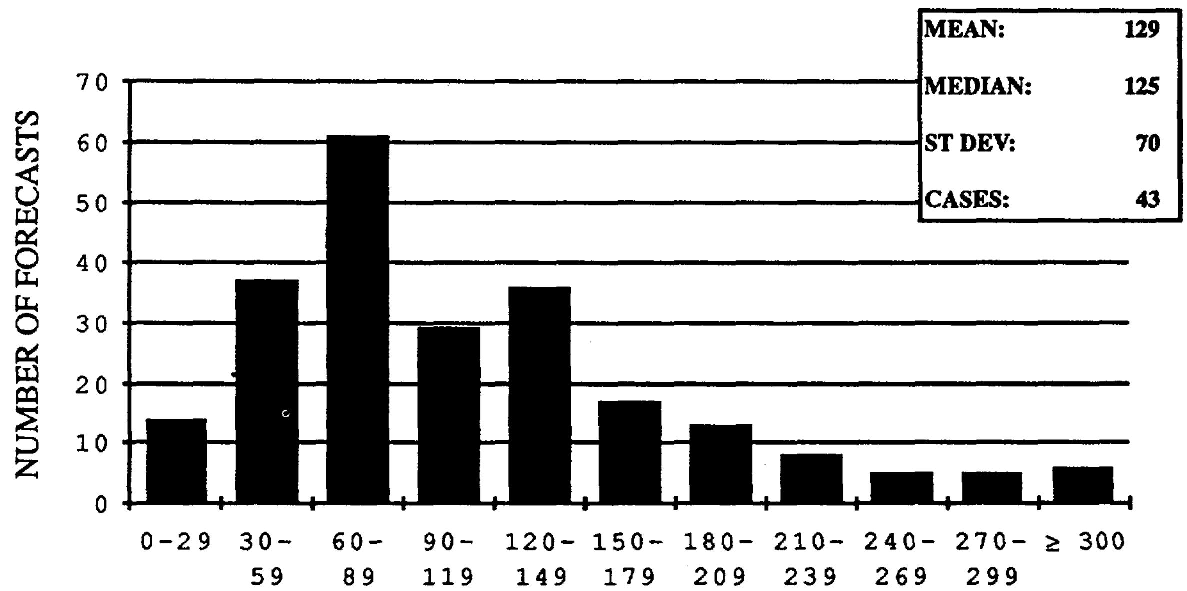


Figure 5-4. Annual mean intensity forecast errors (kt) and 5-year running mean for a) 24-hours, b)48-hours and c) 72-hours in the Northwest Pacific Ocean.



ERROR (NM)

Figure 5-5A. Frequency distribution of initial positiont errors (15 nm increments) for the North Indian Ocean in 1991. The largest error during 1991 was 183 nm (Tropical Cyclone 01A).



ERROR (NM)

Figure 5-5B. Frequency distribution of 24-hour forecast errors (30 nm increments) for the North Indian Ocean in 1991. The largest error during 1991 was 307 nm (Tropical Cyclone 01A).

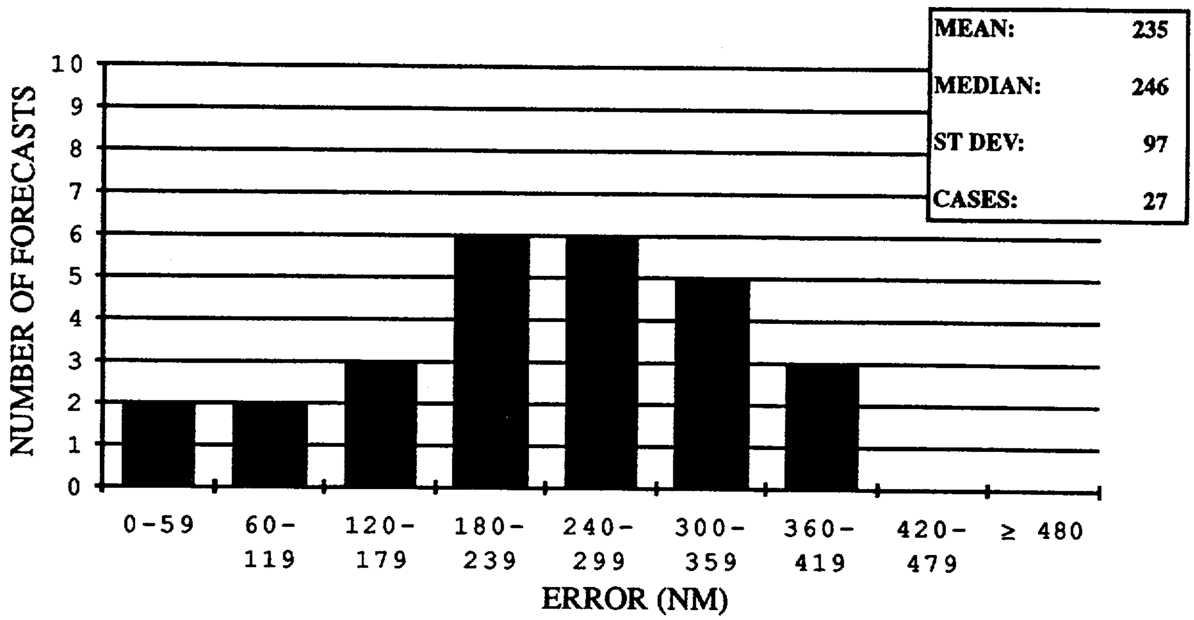


Figure 5-5C. Frequency distribution of 48-hour forecast errors (60 nm increments) for the North Indian Ocean in 1991. The largest error during 1991 was 409 nm (Tropical Cyclone 02B).

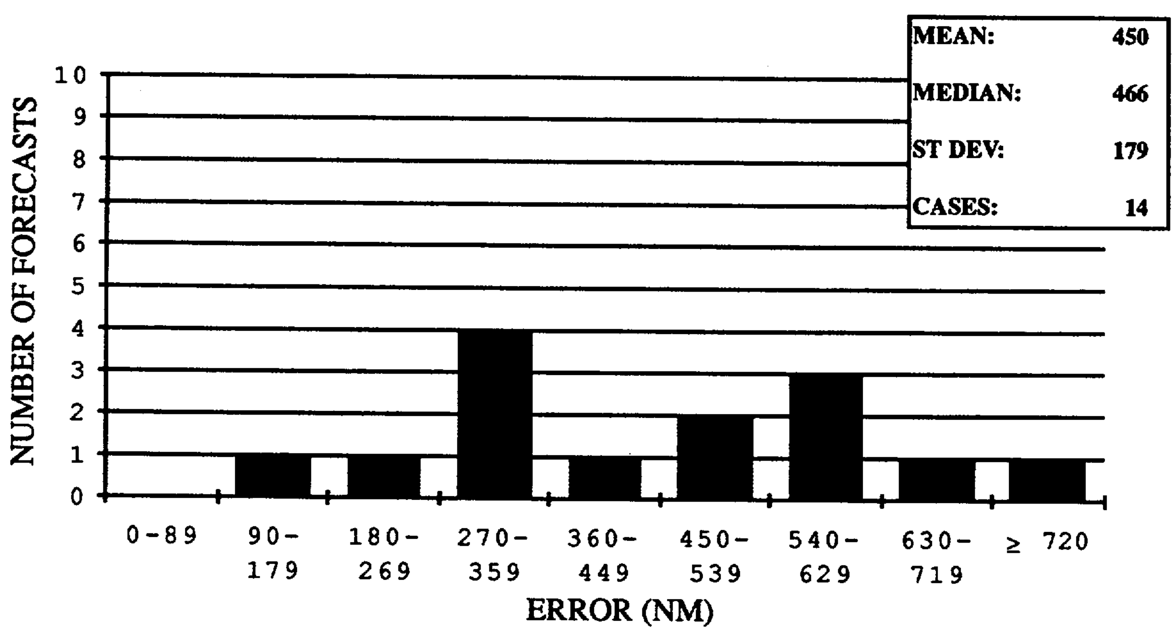


Figure 5-5D. Frequency distribution of 72-hour forecast errors (90 nm increments) for the North Indian Ocean in 1991. The largest error during 1991 was 722 nm (Tropical Cyclone 02B).

TABLE 5-3. JTWC ANNUAL INITIAL POSITION AND FORECAST POSITION ERRORS (NM) 1971-1991 FOR THE NORTH INDIAN OCEAN

YEAR	NUMBER OF WARNINGS	INITIAL POSITION	24-HOUR NUMBER OF FORECASTS	24-HOUR TRACK	24-HOUR ALONG	24-HOUR CROSS	48-HOUR NUMBER OF FORECASTS	48-HOUR TRACK	48-HOUR ALONG	48-HOUR CROSS	72-HOUR NUMBER OF FORECASTS	72-HOUR TRACK	72-HOUR ALONG	72-HOUR CROSS
1971	10	N/A	7	232	183	127	2	296	72	281	N/A			
1972	24	75	20	217	87	188	10	299	247	130	N/A			
1973	28	55	24	182	134	97	17	238	165	159	N/A			
1974	7	38	6	137	95	88	4	228	156	138	N/A			
1975	42	61	37	145	101	87	25	104	119	164	N/A			
1976	21	42	16	138	74	105	7	292	157	215	N/A			
1977	36	36	31	122	69	84	19	202	147	109	N/A			
1978	32	43	28	133	90	82	17	278	193	161	N/A			
1979	93	46	63	151	96	95	38	93	25	88	17	437	251	320
1980	14	41	7	115	81	71	2	176	120	109	1	167	97	137
1981	41	28	29	109	76	63	17	368	292	209	5	197	150	111
1982	55	35	37	138	110	68	18	153	137	53	7	762	653	332
1983	18	38	7	117	90	50	2	274	217	139	0			
1984	67	33	42	154	124	67	20	274	217	139	16	338	339	121
1985	53	31	30	122	102	53	8	242	119	194	0			
1986	28	52	16	134	118	53	7	168	131	80	5	269	189	180
1987	83	42	54	144	91	100	25	205	125	140	21	305	219	188
1988	44	34	30	120	89	63	18	219	112	176	12	409	227	303
1989	44	19	33	88	62	50	17	146	94	86	12	216	164	111
1990	46	31	36	101	85	43	24	146	117	67	17	185	130	104
1991	56	38	43	129	107	54	27	235	200	89	14	450	356	178
AVERAGE 71-91:	40	41	28	139	98	80	15	232	155	143	10	334	252	189

NOTE: Cross-track and along-track errors were adopted by the JTWC in 1986. Right-angle errors (used prior to 1986) were re-computed as cross-track and along-track errors after the fact to extend the data base. See Figure 5-1 for the definitions of cross-track and along-track errors.

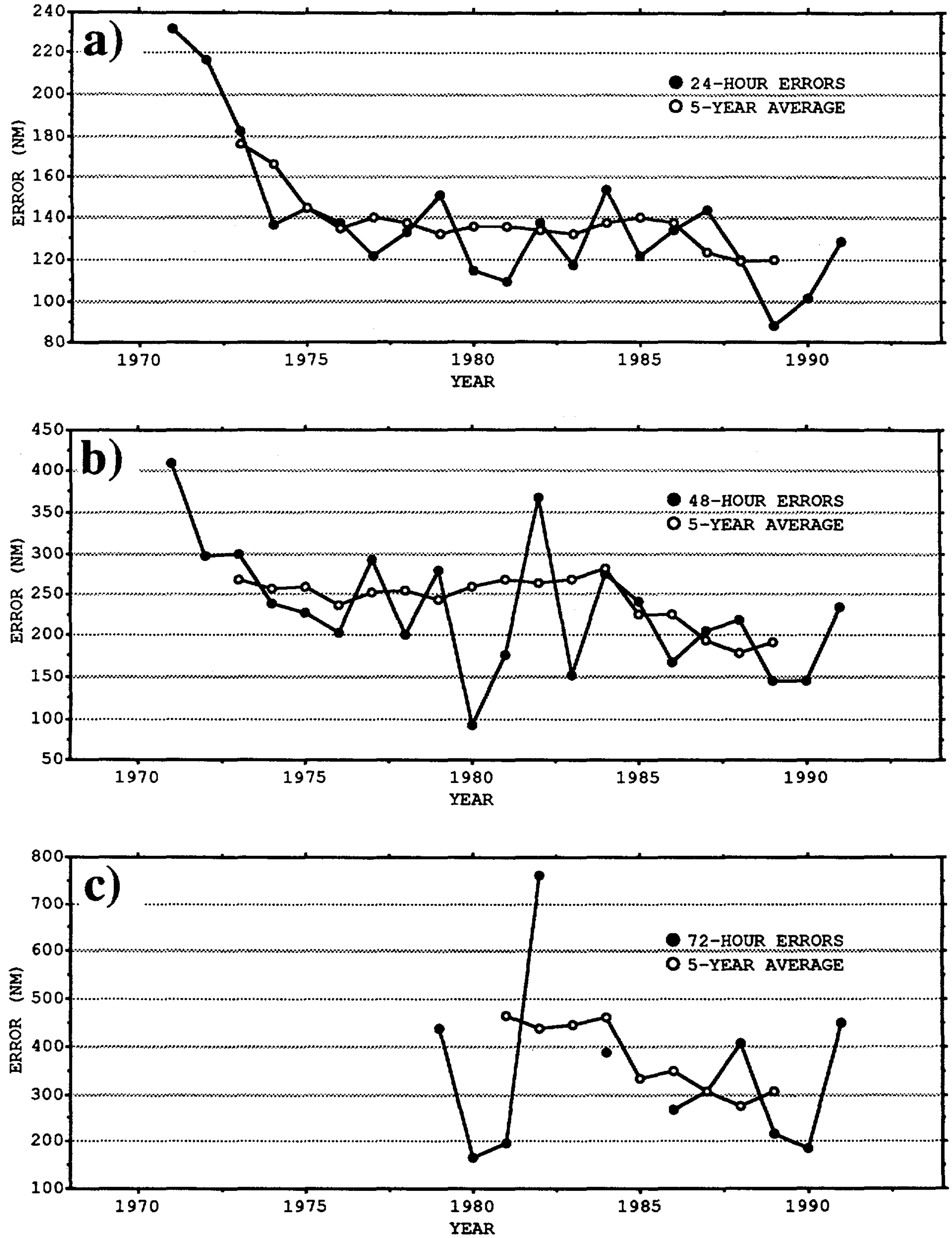


Figure 5-6. Annual mean track errors (nm) and 5-year running mean for a) 24-hours, b) 48-hours and c) 72-hours in the North Indian Ocean. Note that no 72-hour forecasts verified prior to 1979, in 1983 and 1985.

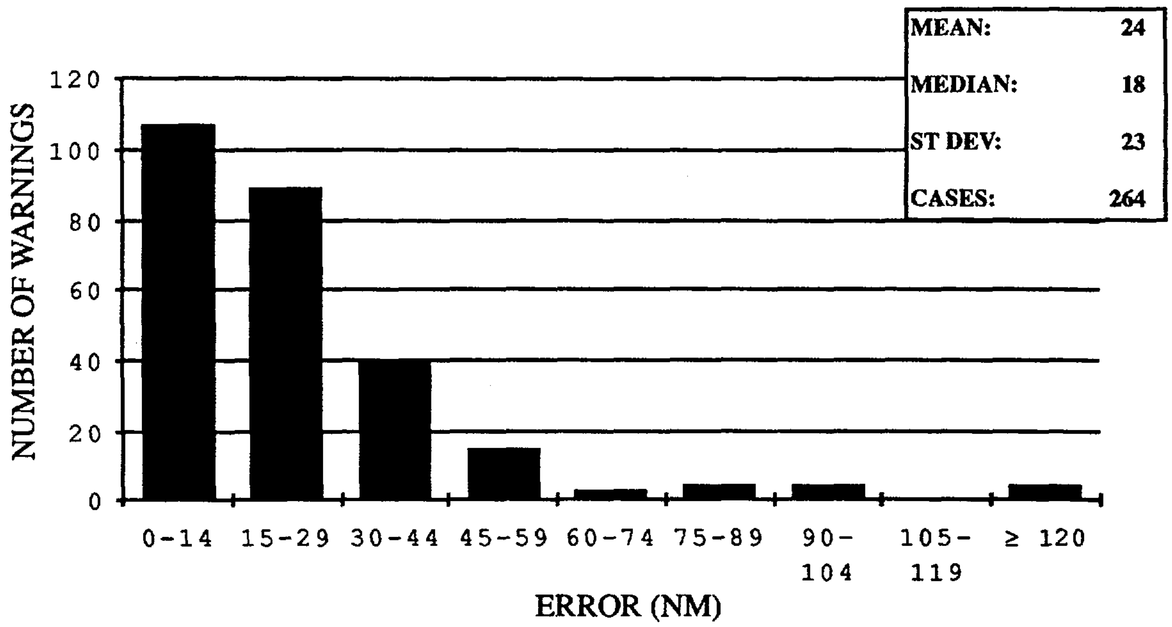


Figure 5-7A. Frequency distribution of initial position errors (15 nm increments) for the South Pacific and South Indian Ocean in 1991. The largest error during 1991 was 154 nm (Tropical Cyclone 08S).

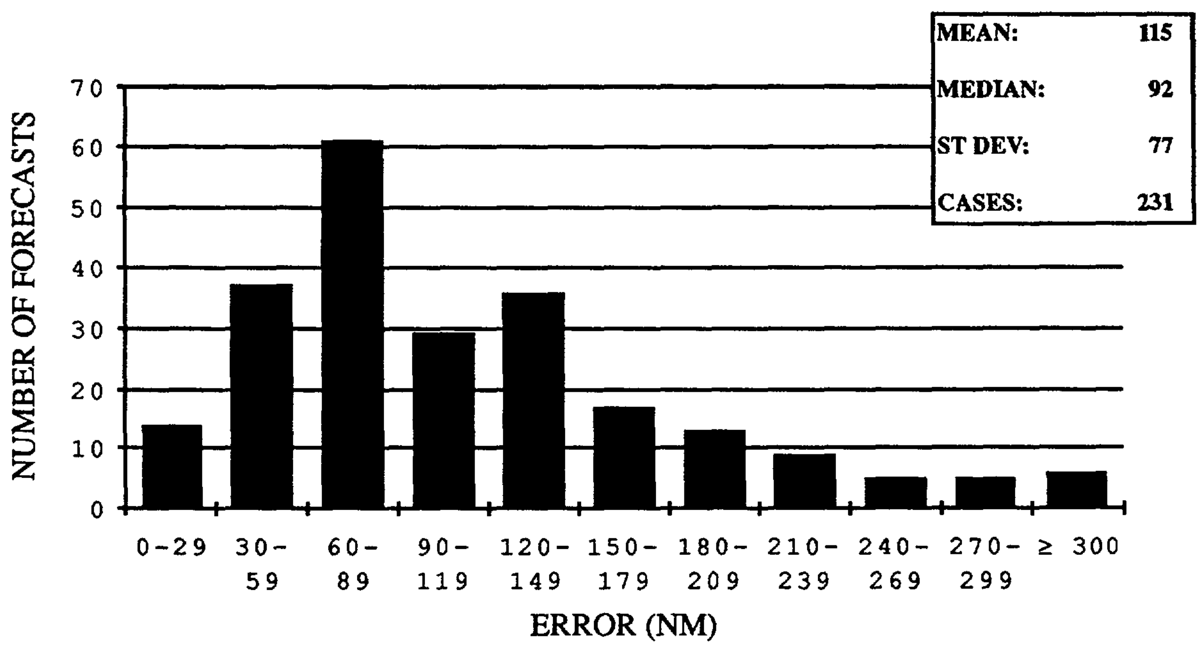


Figure 5-7B. Frequency distribution of 24-hour forecast errors (30 nm increments) for the South Pacific and South Indian Ocean in 1991. The largest error during 1991 was 386 nm (Tropical Cyclone 12S).

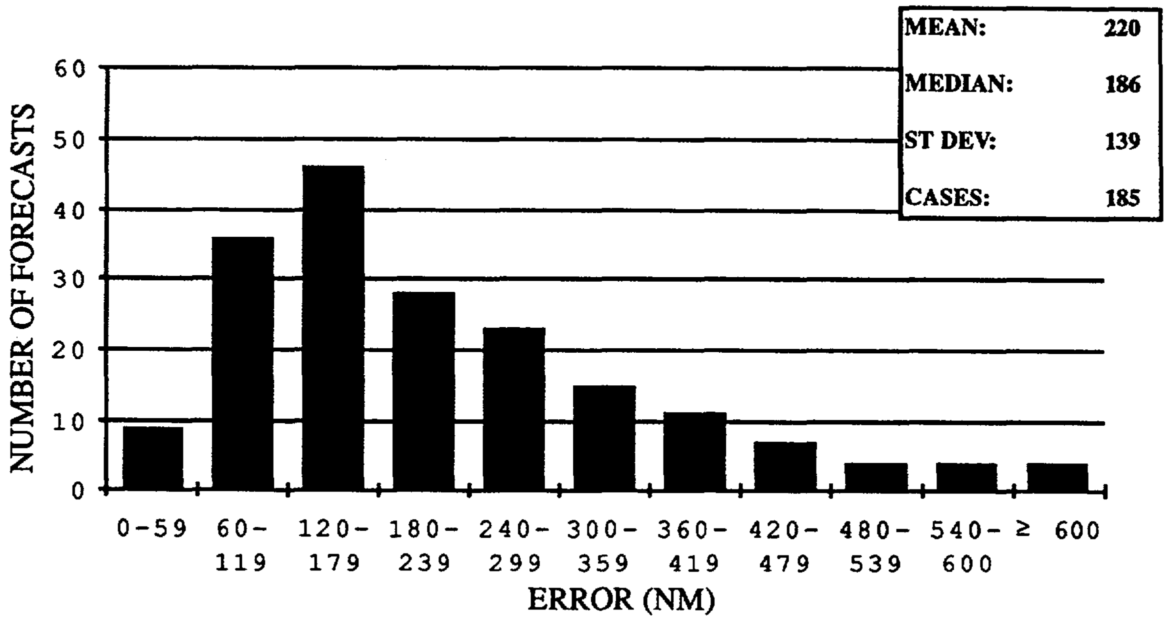


Figure 5-7C. Frequency distribution of 48-hour forecast errors (60 nm increments) for the South Pacific and South Indian Ocean in 1991. The largest error during 1991 was 716 nm (Tropical Cyclone 17S).

TABLE 5-4. JTWC ANNUAL INITIAL POSITION AND FORECAST POSITION ERRORS (NM) 1981-1991 FOR THE SOUTHERN HEMISPHERE

YEAR	NUMBER OF WARNINGS	INITIAL POSITION	24-HOUR NUMBER OF FORECASTS	24-HOUR TRACK	24-HOUR ALONG	24-HOUR CROSS	48-HOUR NUMBER OF FORECASTS	48-HOUR TRACK	48-HOUR ALONG	48-HOUR CROSS
1981	226	48	190	165	103	106	140	315	204	201
1982	275	38	238	144	98	86	176	274	188	164
1983*	191	35	163	130	88	77	126	241	158	145
1984	301	36	252	133	90	79	191	231	159	134
1985*	306	36	257	134	92	79	193	236	169	132
1986*	279	40	227	129	86	77	171	262	169	164
1987*	189	46	138	145	94	90	101	280	153	138
1988*	204	34	99	146	98	83	48	290	246	144
1989*	287	31	242	124	84	73	186	240	166	136
1990*	272	27	228	143	105	74	177	263	178	152
1991	264	24	231	115	75	69	185	220	152	129
AVERAGE 78-91:	254	36	206	136	92	80	255	255	175	150

NOTE: Cross-track and along-track errors were adopted by the JTWC in 1986. Right-angle errors (used prior to 1986) were re-computed as cross-track and along-track errors after the fact to extend the data base.

See Figure 5-1 for the definitions of cross-track and along-track errors.

* These statistics are for JTWC forecasts only. NWOC errors are not included.

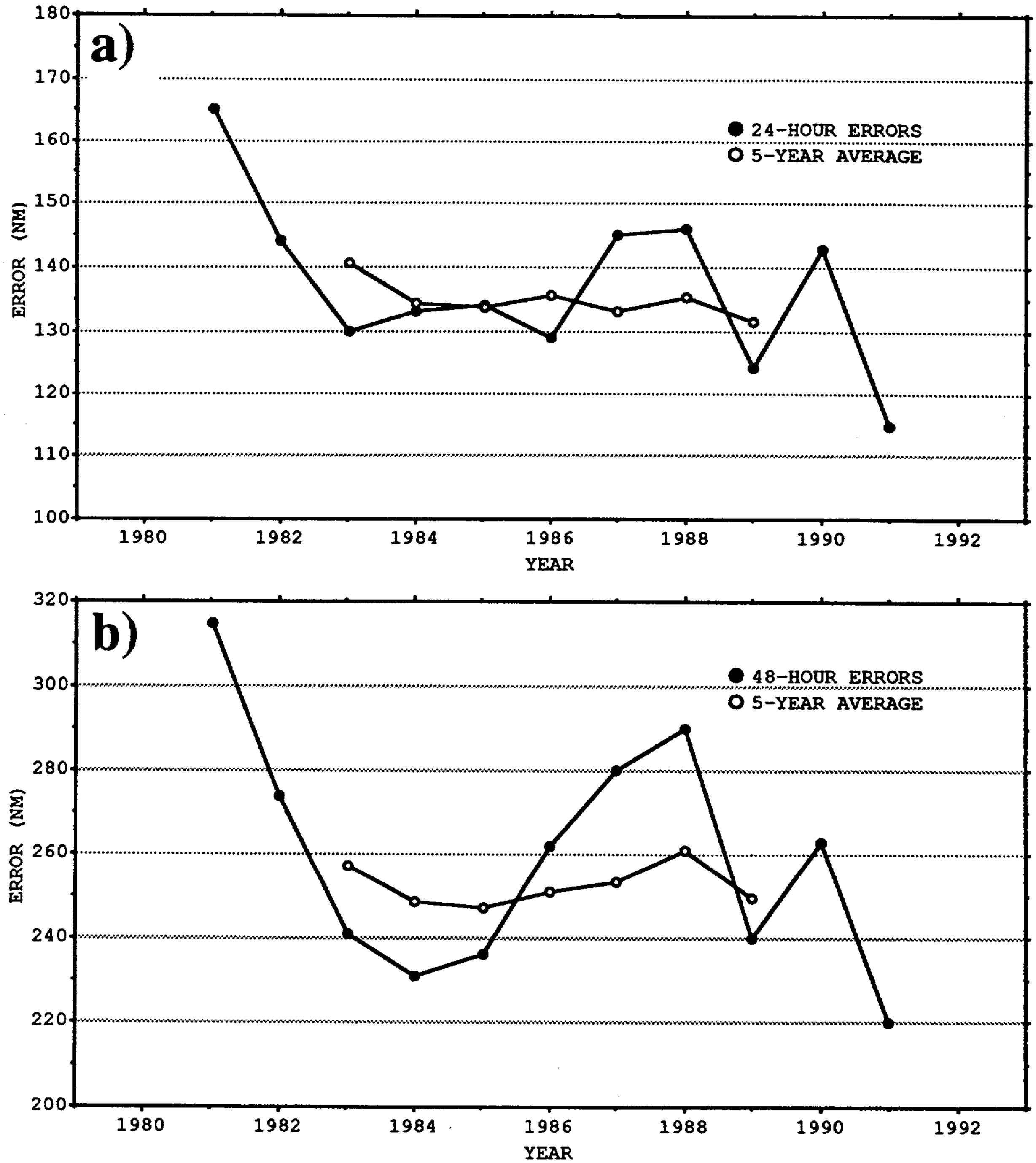


Figure 5-8. Annual mean track forecast errors and the 5-year running mean for a) 24-hours and b) 48-hours in the South Pacific and South Indian Oceans.

5.2 COMPARISON OF OBJECTIVE TECHNIQUES

JTWC uses a variety of objective techniques for guidance in the warning development process. Multiple techniques are required, because each technique has particular strengths and weaknesses which vary by basin, numerical model initialization, time of year, synoptic situation and forecast period. The accuracy of objective aid forecasts depends on both the specified position and the past motion of the tropical cyclone as determined by the working best track. JTWC initializes its objective techniques using the extrapolated warning position.

An initiative is presently underway to convert most of the objective techniques that currently run on mainframe computers at FNOC to desktop computer versions that run on ATCF workstations. These will eventually replace the FNOC-generated techniques. Three of these new aids have been received and are under evaluation.

Unless stated otherwise, all the objective techniques discussed below run in all basins covered by JTWC's AOR and provide forecast positions at 24-, 48-, and 72-hours unless the technique aborts prematurely during computations. The techniques can be divided into six general categories: extrapolation, climatology and analogs, statistical, dynamic, hybrids, and empirical or analytical.

5.2.1 EXTRAPOLATION (XTRP) — Past speed and direction are computed using the rhumb line distance between the current and 12-hour old positions of the tropical cyclone. Extrapolation from the current warning position is used to compute forecast positions.

5.2.2 CLIMATOLOGY and ANALOGS

5.2.2.1 CLIMATOLOGY (CLIM) — Employs time and location windows relative to the current position of the storm to determine which historical storms will be used to compute the forecast. The historical data base is 1945-1981 for the Northwest Pacific, and 1900 to 1990 for the rest of JTWC's AOR. A second climatology-based technique exists on JTWC's Macintosh®™ II computers. It employs data bases from 1945 to 1991 and from 1970 to 1991. The latter is referred to as the satellite-era data base. Objective intensity forecasts are available from these data bases. Scatter diagrams of expected tropical cyclone motion at bifurcation points are also available from these data bases.

5.2.2.2 ANALOGS — JTWC's analog and climatology techniques use the same historical data base, except that the analog approach imposes more restrictions on which storms will be used to compute the forecast positions. Analogs in all basins must satisfy time, location, speed, and direction windows, although the window definitions are distinctly different in the Northwest Pacific. In this basin, acceptable analogs are also ranked in terms of a similarity index that includes the above parameters and: storm size and size change, intensity and intensity change, and heights and locations of the 700-mb subtropical ridge and upstream midlatitude trough. In other basins, all acceptable analogs receive equal weighting and a persistence bias is explicitly added to the forecast. Inside the Northwest Pacific, analog weighting is varied using the similarity index, and a persistence bias is implicitly incorporated by rotating the analog tracks so that they initially match the 12-hr old motion of the current storm. In the Northwest Pacific, a forecast based on all acceptable analogs called TOTL, as well as a forecast based only on historical recurvers called RECR are available. Outside this basin, only the TOTL technique is available.

5.2.3 STATISTICAL

5.2.3.1 CLIMATOLOGY AND PERSISTENCE (CLIP) — A statistical regression technique that is based on climatology, current position and 12-hour and 24-hour past movement. This technique is used as a crude baseline against which to measure the forecast skill of other more sophisticated techniques. CLIP in the Northwest Pacific uses third-order regression equations and is based on the work of Xu and Neumann (1985). CLIP has been available outside this basin since mid-1990, with regression coefficients recently recomputed by FNOC based on the updated 1900-1989 data base.

5.2.3.2 COLORADO STATE UNIVERSITY MODEL (CSUM) — A statistical-dynamical technique based on the work of Matsumoto (1984). Predictor parameters include the current and 24-hr old position of the storm, heights from the current and 24-hr old NOGAPS 500-mb analyses, and heights from the 24-hr and 48-hr NOGAPS 500 mb prognoses. Height values from 200-mb fields are substituted for storms that have an intensity exceeding 90 knots and are located north of the subtropical ridge. Three distinct sets of regression equations are used depending on whether the storm's direction of motion falls into "below," "on," or "above" the subtropical ridge categories. During the development of the regression equation coefficients for CSUM, the so-called "perfect prog" approach was used, in which verifying analyses were substituted for the numerical prognoses that are used when CSUM is run operationally. Thus, CSUM was not "tuned" to any particular version of NOGAPS, and in fact, the performance of CSUM should presumably improve as new versions of NOGAPS improve. CSUM runs only in the Northwest Pacific, South China Sea, and North Indian Ocean basins.

5.2.4 DYNAMIC

5.2.4.1 NOGAPS VORTEX TRACKING ROUTINE (NGPS) — This objective technique follows the movement of the point of minimum height on the 1000 mb pressure surface analyzed and predicted by NOGAPS. A search in the expected vicinity of the storm is conducted every six hours through 72 hours, even if the tracking routine temporarily fails to discern a minimum height point. Explicit insertion of a tropical cyclone bogus via data provided over TYMNET by JTWC began in mid-1990, and should improve the ability of the NOGAPS technique to track the vortex.

5.2.4.2 ONE-WAY INFLUENCE TROPICAL CYCLONE MODEL (OTCM) — This technique is a coarse resolution (205 km grid), three layer, primitive equation model with a horizontal domain of 6400 x 4700 km. OTCM is initialized using 6-hour or 12-hour prognostic fields from the latest NOGAPS run, and the initial fields are smoothed and adjusted in the vicinity of the storm to induce a persistence bias into OTCM's forecast. A symmetric bogus vortex is then inserted, and the boundaries updated every 12 hours by NOGAPS fields as the integration proceeds. The bogus vortex is maintained against frictional dissipation by an analytical heating function. The forecast positions are based on the movement of the vortex in the lowest layer of the model (effectively 850-mb).

5.2.4.3 FNOC BETA AND ADVECTION MODEL (FBAM) — This model is an adaptation of the Beta and Advection model used by NMC. The forecast motion results from a calculation of environmental steering and an empirical correction for the observed vector difference between that steering and the 12-hour old storm motion. The steering is computed from the NOGAPS Deep Layer Mean (DLM)

wind fields which are a weighted average of the wind fields computed for the 1000-mb to 100-mb levels. The difference between past storm motion and the DLM steering is treated as if the storm were a Rossby wave with an "effective radius" propagating in response to the horizontal gradient of the coriolis parameter, Beta. The forecast proceeds in one-hour steps, recomputing the effective radius as Beta changes with storm latitude, and blending in a persistence bias for the first 12 hours.

5.2.5 HYBRIDS

5.2.5.1 HALF PERSISTENCE AND CLIMATOLOGY (HPAC) — Forecast positions are generated by equally weighting the forecasts given by XTRP and CLIM.

5.2.5.2 COMBINED CONFIDENCE WEIGHTED FORECASTS (CCWF) — An optimal blend of objective techniques produced by the ATCF. The ATCF blends the selected techniques (currently OTCM, CSUM and HPAC) by using the inverse of the covariance matrices computed from historical and real-time cross-track and along-track errors as the weighting function.

5.2.6 EMPIRICAL OR ANALYTICAL

5.2.6.1 DVORAK — An estimation of a tropical cyclone's current and 24-hour forecast intensity is made from the interpretation of satellite imagery (Dvorak, 1984) . These intensity estimates are used with other intensity related data and trends to forecast short-term tropical cyclone intensity.

5.2.6.2 MARTIN/HOLLAND — The technique adapts an earlier work (Holland, 1980) and specifically addresses the need for realistic 30-, 50- and 100-kt(15-,26- and 51-m/sec) wind radii around tropical cyclones. It solves equations for basic gradient wind relations within the tropical cyclone area, using input parameters obtained from enhanced infrared satellite imagery. The diagnosis also includes an asymmetric area of winds caused by tropical cyclone movement. Satellite-derived size and intensity parameters are also used to diagnose internal steering components of tropical cyclone motion known collectively as "beta-drift".

5.2.6.3 TYPHOON ACCELERATION PREDICTION TECHNIQUE (TAPT) — This technique (Weir, 1982) utilizes upper-tropospheric and surface wind fields to estimate acceleration associated with the tropical cyclone's interaction with the mid-latitude westerlies. It includes guidelines for the duration of acceleration, upper limits and probable path of the cyclone.

5.3 TESTING AND RESULTS

A comparison of selected techniques is included in Table 5-5 for all Northwest Pacific tropical cyclones; Table 5-6 for all North Indian Ocean tropical cyclones and Table 5-7 for the Southern Hemisphere. In these tables, "x-axis" refers to techniques listed vertically. For example (Table 5-8) in the 743 cases available for a (homogeneous) comparison, the average forecast error at 24 hours was 111 nm (205 km) for CSUM and 117 nm (216 km) for FBAM. The difference of 6 nm (11 km) is shown in the lower right. (Differences are not always exact, due to computational round-off which occurs for each of the cases available for comparison).

TABLE 5-5

1991 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE NORTHWEST PACIFIC (1 JAN 1991 - 31 DEC 1991)

Number of Cases	X-Axis Technique Error
Y-Axis Technique Error	Error Difference (Y-X)

24-HOUR MEAN FORECAST ERROR (NM)

	JTWC		NGPS		OTCM		CSUM		FBAM		CLIP		HPAC	
JTWC	733	**96**												
	96	0												
NGPS	270	96	272	**138**										
	137	41	138	0										
OTCM	686	95	259	137	761	**116**								
	118	23	113	-24	116	0								
CSUM	706	96	261	136	741	116	778	**112**						
	113	17	112	-24	111	-5	112	0						
FBAM	692	95	257	137	722	115	743	111	759	**117**				
	118	23	128	-9	115	0	117	6	117	0				
CLIP	722	96	270	138	760	116	778	112	759	117	798	**118**		
	118	22	116	-22	117	1	118	6	116	-1	118	0		
HPAC	717	96	268	137	753	116	771	112	752	117	791	118	792	**128**
	129	33	128	-9	127	11	128	16	127	10	128	10	128	0

48-HOUR MEAN FORECAST ERROR (NM)

	JTWC		NGPS		OTCM		CSUM		FBAM		CLIP		HPAC	
JTWC	599	**185**												
	185	0												
NGPS	202	187	207	**221**										
	221	34	221	0										
OTCM	532	182	189	225	618	**194**								
	198	16	196	-29	194	0								
CSUM	579	185	198	215	603	194	663	**212**						
	217	32	222	7	210	16	212	0						
FBAM	570	183	194	221	588	194	634	213	649	**211**				
	216	33	233	12	208	14	211	-2	211	0				
CLIP	593	185	205	222	617	194	663	212	649	211	680	**232**		
	236	51	241	19	231	37	232	20	232	21	232	0		
HPAC	589	184	203	221	613	195	658	212	643	211	674	232	675	**242**
	248	64	245	24	239	44	242	30	243	32	242	10	242	0

72-HOUR MEAN FORECAST ERROR (NM)

	JTWC		NGPS		OTCM		CSUM		FBAM		CLIP		HPAC	
JTWC	484	**287**												
	287	0												
NGPS	123	292	127	**323**										
	321	29	323	0										
OTCM	394	276	108	323	476	**277**								
	283	7	292	-31	277	0								
CSUM	471	289	122	317	465	277	553	**308**						
	316	27	333	16	292	15	308	0						
FBAM	461	285	118	326	453	277	529	311	539	**316**				
	325	40	335	9	296	19	318	7	316	0				
CLIP	480	287	125	323	475	276	553	308	539	316	565	**350**		
	354	67	373	50	346	70	351	43	352	36	350	0		
HPAC	480	287	125	323	473	277	551	308	537	316	563	351	564	**361**
	373	86	387	64	335	58	363	55	363	47	361	10	361	0

JTWC - JTWC Forecast
OTCM - One-Way Tropical Cyclone Model
FBAM - FNOC Beta and Advection Model
HPAC - Half Persistence and Climatology
NGPS - Navy-Operational Global-Atmospheric Prediction System
CSUM - Colorado State University Model
CLIP - Climatology/Persistence

TABLE 5-6

1991 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE NORTH INDIAN OCEAN (1 JAN 1991 - 31 DEC 1991)

24-HOUR MEAN FORECAST ERROR (NM)

	JTWC		OTCM		FBAM		CLIP		HPAC		TOTL		CLIM	
JTWC	43	**129**												
	129	0												
OTCM	40	125	45	**133**										
	131	6	133	0										
FBAM	40	125	45	133	45	**154**								
	146	21	154	21	154	0								
CLIP	40	125	45	133	45	154	45	**150**						
	151	26	150	17	150	-4	150	0						
HPAC	35	110	40	125	40	152	40	134	40	**130**				
	130	20	130	5	130	-22	130	-4	130	0				
TOTL	31	120	34	130	34	155	34	128	31	121	34	**148**		
	146	26	148	18	148	-7	148	20	138	17	148	0		
CLIM	35	110	40	125	40	152	40	134	40	130	31	138	40	**123**
	122	12	123	-2	123	-29	123	-11	123	-7	116	-22	123	0

Number of Cases	X-Axis Technique Error
Y-Axis Technique Error	**Error Difference (Y-X)**

48-HOUR MEAN FORECAST ERROR (NM)

	JTWC		OTCM		FBAM		CLIP		HPAC		TOTL		CLIM	
JTWC	27	**235**												
	235	0												
OTCM	23	230	28	**258**										
	259	29	258	0										
FBAM	25	233	28	258	30	**272**								
	257	24	270	12	272	0								
CLIP	25	233	28	258	30	272	30	**277**						
	274	41	282	24	277	5	277	0						
HPAC	23	228	26	252	28	259	28	271	28	**224**				
	233	5	228	-24	224	-35	224	-47	224	0				
TOTL	16	245	16	261	18	232	18	261	18	237	18	**285**		
	271	26	280	19	285	53	285	24	285	48	285	0		
CLIM	23	228	26	252	28	259	28	271	28	224	18	285	28	**207**
	210	-18	217	-35	207	-52	207	-64	207	-17	199	-86	207	0

72-HOUR MEAN FORECAST ERROR (NM)

	JTWC		OTCM		FBAM		CLIP		HPAC		TOTL		CLIM	
JTWC	14	**450**												
	450	0												
OTCM	12	470	15	**471**										
	513	43	471	0										
FBAM	14	450	15	471	17	**321**								
	284	-166	324	-147	321	0								
CLIP	14	450	15	471	17	321	17	**412**						
	402	-48	429	-42	412	91	412	0						
HPAC	13	464	13	483	15	283	15	383	15	**386**				
	410	-54	401	-82	386	103	386	3	386	0				
TOTL	9	468	7	553	9	311	9	419	9	419	9	**472**		
	472	4	468	-85	472	161	472	53	472	53	472	0		
CLIM	13	464	13	483	15	283	15	383	15	386	9	472	15	**327**
	296	-168	373	-110	327	44	327	-56	327	-59	313	-159	327	0

JTWC - JTWC Forecast
OTCM - One-Way Tropical Cyclone Model
FBAM - FNOC Beta and Advection Model
CLIP - Climatology/Persistence
HPAC - Half Persistence and Climatology
TOTL - Total Analog
CLIM - Climatology

TABLE 5-7

1991 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE SOUTHERN HEMISPHERE (1 JUL 1990 - 30 JUN 1991)

24-HOUR MEAN FORECAST ERROR (NM)

	JTWC		OTCM		CLIP		HPAC		TOTL		CLIM		XTRP	
JTWC	232	118												
	118	0												
OTCM	204	116	266	124										
	122	6	124	0										
CLIP	215	118	260	124	278	163								
	156	38	153	29	163	0								
HPAC	213	116	256	121	271	158	273	135						
	132	16	134	13	135	-23	135	0						
TOTL	140	112	172	129	185	158	185	135	185	138				
	135	23	135	6	138	-20	138	3	138	0				
CLIM	214	116	260	122	271	158	273	135	185	138	277	164		
	155	39	160	38	164	6	164	29	166	28	164	0		
XTRP	211	120	256	125	272	164	267	137	184	138	267	166	274	147
	146	26	144	19	147	-17	143	6	134	-4	143	-23	147	0

Number of Cases	X-Axis Technique Error
Y-Axis Technique Error	Error Difference (Y-X)

48-HOUR MEAN FORECAST ERROR (NM)

	JTWC		OTCM		CLIP		HPAC		TOTL		CLIM		XTRP	
JTWC	186	**223**												
	223	0												
OTCM	152	227	208	**229**										
	230	3	229	0										
CLIP	172	224	204	230	233	**269**								
	263	39	256	26	269	0								
HPAC	171	219	203	228	229	264	231	**240**						
	238	19	233	5	240	-24	240	0						
TOTL	114	218	131	252	153	268	152	245	153	**267**				
	266	48	268	16	267	-1	267	22	267	0				
CLIM	171	219	205	228	229	264	231	240	152	267	233	**275**		
	260	41	262	34	275	11	275	35	288	21	275	0		
XTRP	169	227	200	232	227	271	225	243	152	268	225	278	229	**284**
	287	60	283	51	284	13	279	36	262	-6	279	1	284	0

72-HOUR MEAN FORECAST ERROR (NM)

	OTCM		CLIP		HPAC		TOTL		CLIM		XTRP	
OTCM	160	**342**										
	342	0										
CLIP	157	342	190	**350**								
	337	-5	350	0								
HPAC	158	341	188	352	190	**338**						
	331	-10	337	-15	338	0						
TOTL	93	374	118	348	118	359	118	**406**				
	418	44	406	58	406	47	406	0				
CLIM	159	343	188	352	190	338	118	406	191	**372**		
	377	34	370	18	370	32	401	-5	372	0		
XTRP	154	344	185	353	185	343	117	407	185	373	187	**425**
	419	75	424	71	427	84	405	-2	427	54	425	0

JTWC - JTWC Forecast
OTCM - One-Way Tropical Cyclone Model
CLIP - Climatology/Persistence
HPAC - Half Persistence and Climatology
TOTL - Total Analog
CLIM - Climatology
XTRP - Extrapolation

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6. TROPICAL CYCLONE WARNING VERIFICATION STATISTICS

6.1 GENERAL

Due to the rapid growth of microcomputers in the meteorological community and to save publishing costs, tropical cyclone track data (with best track, initial warning, 24-, 48- and 72-hour JTWC forecasts) and fix data (satellite, aircraft, radar and synoptic) are now available separately upon request. The data will be in ASCII format on 5.25 inch "floppy" or 3.5 inch diskettes and will fill two diskettes (or one high density diskette). These data include the western North Pacific Ocean (1 January - 31 December 1991) on one and North Indian Ocean (1 January - 31 December 1991), and South Western Pacific and South Indian Oceans (1 July 1990 - 30 June 1991) on the other. Agencies or individuals desiring these data sets should send the appropriate number of diskettes to NAVOCEANCOMCEN/ JTWC Guam with their request. When the request and your diskettes are received, the data will be copied onto your diskettes and returned with an explanation of the data formats.

6.2 WARNING VERIFICATION STATISTICS

a. WESTERN NORTH PACIFIC

This section includes verification statistics for each warning in the western North Pacific during 1991.

JTWC FORECAST TRACK AND INTENSITY ERRORS BY WARNING

TROPICAL STORM SHARON (01W)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91030518	1	5.9N	149.3E	25	8	16			-10			-14			0	0		
91030606	2	6.2N	147.9E	30	18	25	51	100	-17	30	30	19	42	95	-5	-5	-5	-5
91030612	3	6.4N	147.3E	30	13	34	80	89	25	54	54	24	60	71	0	0	-5	-5
91030618	4	6.5N	146.6E	30	8	66	91	80	67	78	44	7	48	68	0	-5	-5	-10
91030700	5	6.6N	146.0E	30	30	104	134	106	104	114	74	13	71	77	0	-10	-10	-10
91030706	6	6.6N	145.3E	35	12	46	68	38	36	42	12	30	54	36	0	-5	-10	-5
91030712	7	6.5N	144.6E	35	53	109	139	143	54	72	0	95	119	-143	0	-10	-10	-5
91030718	8	6.3N	144.1E	40	55	119	154	168	96	110	117	71	108	122	0	-10	-10	10
91030800	9	6.1N	143.5E	45	35	113	167	185	-6	30	81	-113	-164	-167	-5	0	5	30
91030806	10	6.1N	142.9E	45	41	107	144	203	6	66	119	-107	-128	-165	0	0	10	35
91030812	11	6.1N	142.2E	50	8	33	16	53	24	15	13	-24	-8	-52	0	5	15	35
91030818	12	6.1N	141.5E	50	16	32	0	69	32	0	-13	-7	0	-68	0	-5	15	35
91030900	13	6.1N	140.8E	55	8	26	25	85	15	-12	-23	-22	-23	-82	0	0	25	40
91030906	14	6.1N	140.0E	55	5	17	29	97	6	-11	2	-17	-28	-98	0	5	30	40
91030912	15	6.1N	139.0E	55	5	55	89	131	-51	-89	-96	22	9	-90	0	10	30	40
91030918	16	6.2N	138.3E	60	13	72	102	174	-67	-101	-105	28	-17	-140	0	25	45	60
91031000	17	6.3N	137.6E	60	43	97	109	196	-81	-109	-147	55	0	-131	5	30	50	55
91031006	18	6.6N	136.8E	55	72	110	108	212	-91	-104	-141	62	-28	-159	10	35	55	50
91031012	19	6.8N	136.1E	55	50	49	138	219	-44	-16	-66	-23	-137	-209	5	20	20	20
91031018	20	7.1N	135.3E	50	42	81	159	248	-37	12	-79	-72	-159	-236	10	20	20	25
91031100	21	7.3N	134.5E	45	29	197	371	512	9	84	3	-197	-362	-512	5	5	0	10
91031106	22	7.6N	133.4E	40	60	204	337	468	25	33	-186	-203	-336	-430	0	0	0	5
91031112	23	7.9N	132.3E	40	90	229	312	474	35	37	-142	-227	-310	-453	0	0	0	5
91031118	24	8.1N	131.1E	40	86	207	278	468	64	23	-148	-197	-277	-445	0	0	5	5
91031200	25	8.3N	130.0E	35	21	13	40	205	-8	-27	43	-11	-30	-201	0	10	20	25
91031206	26	8.6N	128.7E	35	36	51	30	171	-45	-30	59	23	-6	-161	0	15	20	25
91031212	27	9.0N	127.4E	35	30	71	46	182	-66	-32	89	28	-33	-159	0	15	20	25

TROPICAL STORM SHARON (01W) (CONTINUED)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91031218	28	9.5N	126.4E	35	36	68	71	184	-55	-3	79	41	-71	-167	0	20	25	30
91031300	29	10.1N	125.5E	35	17	21	229		18	70		-12	-219		0	10	15	
91031306	30	10.6N	124.5E	30	11	54	256		43	138		-35	-217		0	5	15	
91031312	31	11.1N	123.5E	30	25	78	235		79	184		7	-146		0	5	15	
91031318	32	11.5N	122.5E	25	88	85	226		79	145		-35	-175		5	5	15	
91031400	33	11.9N	121.5E	25	24													
				Average	33	81	136	195	43	60	72	57	109	175	2	9	17	24
				# Cases	33	32	31	27	32	31	27	32	31	27	33	32	31	27

TYPHOON TIM (02W)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91032100	1	6.6N	156.6E	30	21	71	251	538	-69	-177	-172	-20	-179	-511	0	0	-10	-5
91032106	2	7.1N	155.8E	30	5	117	318	626	-111	-230	-154	-39	-221	-607	0	5	-10	0
91032112	3	7.8N	155.1E	35	18	151	380	716	-141	-282	-179	-55	-256	-694	-5	0	-10	0
91032118	4	8.7N	154.5E	35	38	185	448	787	-118	-221	-249	-144	-390	-748	0	0	-10	10
91032200	5	9.7N	154.0E	40	13	124	354	581	-105	-145	-178	-66	-324	-554	-5	-5	0	20
91032206	6	10.7N	153.5E	40	18	69	253	389	-70	-133	-288	0	-215	-262	-5	-15	-5	0
91032212	7	11.6N	153.0E	45	24	160	338	418	-82	-87	-241	-138	-328	-343	-5	-15	-5	5
91032218	8	12.6N	152.7E	50	13	175	356	402	-81	-146	-402	-155	-325	21	0	-5	0	5
91032300	9	13.6N	152.5E	60	23	126	315		-99	-195		-79	-248		0	5	10	
91032306	10	14.7N	152.4E	65	26	143	303		-68	-205		-126	-224		-5	5	10	
91032312	11	15.7N	152.6E	65	8	136	230		-120	-224		-67	-56		0	0	10	
91032318	12	16.6N	152.9E	70	6	127	211		-116	-109		-53	181		0	0	5	
91032400	13	17.4N	153.4E	65	8	82			-79			24			0	5		
91032406	14	18.1N	154.0E	65	8	99			-91			41			0	5		
91032412	15	18.8N	154.8E	65	38	228			71			217			0	10		
91032418	16	19.5N	155.6E	60	79	320			292			131			0	10		
91032500	17	20.0N	156.4E	55	36										0			
91032506	18	20.4N	156.9E	50	23										0			
91032512	19	20.8N	157.4E	45	5										0			
91032518	20	21.2N	157.7E	40	8										-5			
				Average	21	145	313	557	107	179	232	84	245	467	2	5	7	6
				# Cases	20	16	12	8	16	12	8	16	12	8	20	16	12	8

TROPICAL STORM VANESSA (03W)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91042312	1	8.2N	130.2E	25	5	53	74	68	18	-11	-1	-50	-73	-69	5	5	10	5
91042318	2	8.5N	128.9E	30	13	24	84	114	0	-37	-32	-24	-76	-110	0	5	10	5
91042400	3	8.7N	127.7E	30	11	84	150	164	75	98	71	-38	-114	-148	0	10	5	5
91042406	4	8.9N	126.5E	30	8	119	156	138	99	93	54	-67	-126	-128	0	10	0	5
91042412	5	9.2N	125.2E	30	13	84	105	121	-28	-14	29	-80	-105	-118	0	10	5	0
91042418	6	9.5N	123.9E	30	21	63	95	127	-37	-19	58	-51	-93	-114	0	10	5	5
91042500	7	10.0N	122.7E	25	6	13	42	138	-3	-11	-70	-13	-41	-120	0	0	0	10
91042506	8	10.5N	121.4E	25	0	13	66	193	9	25	-4	-10	-62	-193	0	-5	0	15
91042512	9	11.0N	120.2E	30	16	58	71	179	59	72	-69	-4	0	-165	0	0	10	15
91042518	10	11.3N	119.0E	30	29	90	73	136	89	69	-61	-19	24	-122	5	-5	0	5
91042600	11	11.6N	117.8E	35	29	42	141		-2	-104		43	-96		0	-5	5	
91042606	12	11.9N	116.6E	40	13	48	245		-34	-46		-34	-241		-5	-5	10	
91042612	13	12.3N	115.4E	40	11	37	247		1	-85		-38	-233		0	15	30	
91042618	14	12.7N	114.2E	45	5	72	363		-41	-189		-60	-311		0	20	-5	
91042700	15	13.1N	113.0E	45	11	141			-99			-102			0	15		
91042706	16	13.7N	112.0E	45	17	186			-96			-160			0	15		

TROPICAL STORM VANESSA (03W) (CONTINUED)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91042712	17	14.5N	111.2E	40	18	257			-109			-233			0	10		
91042718	18	15.5N	110.8E	35	5	101			-32			-96			0	5		
91042800	19	16.6N	110.8E	30	22										0			
91042806	20	17.8N	110.9E	25	8										0			
				Average	13	83	136	138	46	62	44	62	113	128	1	8	7	7
				# Cases	20	18	14	10	18	14	10	18	14	10	20	18	14	10

SUPER TYPHOON WALT (04W)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91050618	1	7.9N	150.4E	30	36	64	114	189	64	111	175	11	-29	-71	0	0	-5	-35
91050700	2	8.2N	150.1E	35	24	80	147	214	78	133	173	-20	-64	-127	0	0	-10	-35
91050706	3	8.5N	149.7E	35	18	21	97	199	21	86	129	-2	-46	-152	0	-5	-30	-40
91050712	4	8.8N	149.3E	35	24	24	68	165	19	52	65	16	-45	-153	0	-10	-40	-40
91050718	5	9.1N	148.8E	40	6	58	143	278	43	67	117	-39	-126	-253	0	-10	-40	-40
91050800	6	9.3N	148.3E	45	30	100	183	292	46	73	79	-89	-168	-282	0	-10	-35	-20
91050806	7	9.6N	147.7E	50	21	30	85	181	30	45	55	7	-73	-173	0	-25	-35	-20
91050812	8	9.9N	147.1E	55	13	33	123	256	30	42	67	-15	-116	-248	0	-30	-30	-25
91050818	9	10.2N	146.4E	60	11	47	158	309	20	40	84	-43	-153	-298	0	-25	-15	-35
91050900	10	10.5N	145.7E	70	13	72	175	286	36	36	74	-63	-172	-276	0	-20	-15	-35
91050906	11	10.8N	145.0E	90	13	99	221	286	32	46	84	-95	-217	-274	-10	-5	-10	-40
91050912	12	11.1N	144.1E	100	18	93	204	273	29	74	135	-89	-191	-238	0	5	-5	-35
91050918	13	11.5N	143.1E	105	11	89	240	316	39	106	173	-80	-216	-265	-5	0	-25	-40
91051000	14	11.8N	142.0E	110	5	106	265	382	77	184	320	-73	-192	-210	0	-5	-35	-40
91051006	15	12.1N	140.9E	115	13	130	250	344	50	150	274	-121	-200	-209	0	-10	-45	-40
91051012	16	12.4N	139.7E	115	0	103	221	315	56	139	267	-87	-173	-168	10	15	-15	-10
91051018	17	12.7N	138.5E	115	5	88	203	298	39	126	256	-79	-159	-154	5	-20	-40	-40
91051100	18	13.0N	137.1E	115	5	73	148	223	46	131	222	-58	-70	29	0	-30	-40	-40
91051106	19	13.3N	135.6E	120	13	45	120	163	41	118	138	-21	-23	87	-5	-35	-35	-35
91051112	20	13.7N	134.1E	125	8	37	98	117	38	97	67	3	19	97	0	-15	-10	-5
91051118	21	14.1N	132.8E	130	8	75	139	186	38	104	-11	66	93	186	-5	-10	-10	-5
91051200	22	14.4N	131.6E	135	5	37	126	150	7	56	5	37	114	150	-5	0	0	5
91051206	23	14.8N	130.6E	140	13	81	126	116	56	52	-80	59	115	84	-5	0	5	5
91051212	24	15.2N	129.6E	140	13	26	103	182	26	71	-13	4	76	182	-5	0	-5	-10
91051218	25	15.6N	128.6E	135	8	48	90	165	36	34	-63	32	84	154	0	-5	-5	-5
91051300	26	16.0N	127.8E	130	8	48	134	186	20	61	-132	44	120	132	0	-5	-5	-5
91051306	27	16.3N	127.1E	125	6	78	227	264	40	-2	-234	68	227	125	0	-5	-10	-5
91051312	28	16.7N	126.5E	125	6	26	56	211	19	-21	-195	18	53	82	0	-5	-10	-10
91051318	29	17.1N	125.9E	120	0	28	62		-23	-59		-18	-20		0	-5	-5	
91051400	30	17.6N	125.4E	115	18	49	142		-39	-62		-30	-128		-5	-10	-5	
91051406	31	18.2N	125.1E	110	12	45	150		-41	-107		-19	-106		0	-10	-5	
91051412	32	19.0N	124.8E	105	5	49	173		-39	-153		31	83		0	-10	-5	
91051418	33	19.7N	124.7E	100	5	42			-41			8			0	-5		
91051500	34	20.4N	124.7E	95	8	100			-98			-24			0	-10		
91051506	35	21.2N	125.1E	95	8	109			-105			-30			0	-10		
91051512	36	22.2N	125.9E	90	8	129			-96			88			0	0		
91051518	37	23.3N	127.0E	80	16										0			
91051600	38	24.3N	128.6E	75	17										0			
91051606	39	25.3N	130.9E	70	17										0			
91051612	40	26.6N	133.7E	60	0										0			
				Average	12	66	150	234	42	81	128	45	114	168	2	10	18	25
				# Cases	40	36	32	28	36	32	28	36	32	28	40	36	32	28

TYPHOON YUNYA (05W)

DTG	WRN NO.	BEST TRACK LAT	LONG	WIND	POSITION ERRORS 00	24	48	72	X-TRACK 24	48	72	A-TRACK 24	48	72	WIND ERRORS 00	24	48	72
91061300	1	13.3N	125.6E	55	5	54	117	82	44	117	79	32	7	24	-10	-30	15	35
91061306	2	13.5N	125.2E	65	23	78	142	46	72	140	45	31	-26	-11	-15	-35	35	35
91061312	3	13.7N	124.9E	75	8	29	124	300	-13	60	100	-27	-109	-283	-10	-25	35	10
91061318	4	13.9N	124.6E	85	11	57	160	345	1	93	103	-57	-132	-330	-15	-15	40	15
91061400	5	14.2N	124.2E	95	17	93	186	354	40	81	112	-84	-168	-336	0	50	70	55
91061406	6	14.5N	123.6E	105	18	106	238		25	113		-104	-210		5	85	70	
91061412	7	14.8N	123.0E	95	8	59	247		17	17		-57	-247		5	40	35	
91061418	8	15.0N	122.3E	85	23	101	294		46	46		-90	-291		5	40	35	
91061500	9	15.4N	121.7E	65	18	174	386		-46	-8		-168	-387		0	15	25	
91061506	10	15.8N	120.8E	45	33	223			8			-223			0	5		
91061512	11	16.7N	120.2E	40	62	216			34			-213			0	-5		
91061518	12	17.7N	120.0E	35	88	233			30			-232			0	5		
91061600	13	18.8N	119.9E	30	23	29			-1			29			0	5		
91061606	14	20.1N	120.2E	30	12										0			
91061612	15	21.1N	120.6E	30	6										0			
91061700	16	22.6N	121.5E	20	5										10			
				Average	23	112	210	225	29	75	87	103	175	196	4	27	40	30
				# Cases	16	13	9	5	13	9	5	13	9	5	16	13	9	5

TYPHOON ZEKE (06W)

DTG	WRN NO.	BEST TRACK LAT	LONG	WIND	POSITION ERRORS 00	24	48	72	X-TRACK 24	48	72	A-TRACK 24	48	72	WIND ERRORS 00	24	48	72
91070912	1	12.1N	124.6E	25	50	183	277	307	-26	33	103	-182	-276	-290	0	-5	-15	-30
91070918	2	12.9N	123.6E	25	37	143	190	184	-5	91	78	-144	-167	-167	0	-5	-20	-40
91071000	3	13.6N	122.3E	30	40	182	214	261	113	198	191	-143	-82	-178	0	-10	-20	-25
91071006	4	14.1N	120.9E	30	29	122	120	141	85	119	118	-88	-14	-79	0	-10	-20	-20
91071012	5	14.5N	119.4E	35	18	108	94	119	107	89	103	21	31	-61	0	-5	-20	-20
91071018	6	14.8N	118.1E	35	29	91	80	137	87	80	101	27	-1	-94	0	-10	-30	-20
91071100	7	15.0N	116.9E	40	41	86	164	318	43	53	79	-71	-156	-308	0	-10	-10	25
91071106	8	15.3N	115.9E	45	16	49	148	351	-3	39	100	-50	-143	-337	0	-10	0	35
91071112	9	15.6N	114.9E	50	6	30	179	404	-21	60	82	-23	-170	-396	0	-10	0	25
91071118	10	16.0N	114.0E	55	0	49	246		11	98		-48	-226		0	-15	0	
91071200	11	16.5N	113.2E	60	8	85	280		42	113		-74	-257		0	-5	5	
91071206	12	17.2N	112.5E	65	0	108	317		81	165		-72	-271		0	-10	5	
91071212	13	17.8N	111.7E	70	24	162	405		121	246		-109	-322		-5	-10	0	
91071218	14	18.4N	110.8E	80	24	165			133			-98			-5	-15		
91071300	15	19.0N	109.8E	70	16	95			34			-90			5	0		
91071306	16	19.7N	108.9E	65	30	75			2			-76			-5	5		
91071312	17	20.3N	107.9E	65	45	184			108			-151			0	15		
91071318	18	21.1N	106.7E	60	72										5			
91071400	19	21.5N	105.8E	45	55										5			
91071406	20	22.0N	104.9E	35	39										5			
91071412	21	22.4N	103.8E	25	62										5			
				Average	30	113	209	247	60	106	106	86	162	212	2	9	11	27
				# Cases	21	17	13	9	17	13	9	17	13	9	21	17	13	9

TYPHOON AMY (07W)

DTG	WRN NO.	BEST TRACK LAT	LONG	WIND	POSITION ERRORS 00	24	48	72	X-TRACK 24	48	72	A-TRACK 24	48	72	WIND ERRORS 00	24	48	72
91071518	1	14.6N	134.5E	30	97	196	210	294	-196	-192	-201	-13	-86	-215	-5	-20	-35	-60
91071600	2	15.4N	133.7E	35	55	126	156	283	-123	-134	-155	-29	-80	-237	-5	-20	-50	-60
91071606	3	16.2N	132.9E	40	18	110	159	285	81	105	21	-75	-120	-285	-5	-15	-50	-25
91071612	4	16.9N	131.9E	45	11	96	135	264	79	68	-13	-54	-117	-264	0	-10	-35	25
91071618	5	17.3N	130.7E	55	0	37	58	190	38	0	10	2	-59	-190	0	-15	-25	50

TYPHOON AMY (07W) (CONTINUED)

DTG	WRN NO.	BEST TRACK LAT	LONG	WIND	POSITION ERRORS 00	24	48	72	X-TRACK 24	48	72	A-TRACK 24	48	72	WIND ERRORS 00	24	48	72
91071700	6	17.6N	129.6E	60	8	12	127	230	10	-18	-31	-8	-126	-228	0	-20	-25	50
91071706	7	17.9N	128.5E	65	6	24	146	176	-10	-49	-24	-23	-138	-174	0	-25	-10	55
91071712	8	18.3N	127.4E	75	0	53	188		-9	-31		-53	-186		-5	-30	25	
91071718	9	18.7N	126.3E	90	8	102	213		-18	-33		-101	-211		-10	-5	85	
91071800	10	19.3N	125.1E	105	18	131	171		6	27		-131	-169		-10	-5	85	
91071806	11	19.8N	123.8E	115	17	143	191		-28	36		-141	-188		5	25	55	
91071812	12	20.5N	122.4E	125	12	105			10			-105			0	55		
91071818	13	21.4N	120.8E	125	37	128			-13			-128			0	60		
91071900	14	22.3N	119.0E	120	6	71			55			-47			-5	20		
91071906	15	23.0N	117.4E	105	13	77			21			-74			-5	30		
91071912	16	23.6N	116.0E	75	5										15			
91071918	17	24.1N	114.8E	45	28										20			
91072000	18	24.6N	113.6E	35	0										10			
				Average	19	94	159	246	46	63	65	65	134	227	6	24	44	46
				# Cases	18	15	11	7	15	11	7	15	11	7	18	15	11	7

TYPHOON BRENDAN (08W)

DTG	WRN NO.	BEST TRACK LAT	LONG	WIND	POSITION ERRORS 00	24	48	72	X-TRACK 24	48	72	A-TRACK 24	48	72	WIND ERRORS 00	24	48	72
91072100	1	14.6N	125.8E	35	42	86	145	201	55	-16	116	-67	-145	-165	-5	-15	-5	15
91072106	2	15.1N	125.1E	40	23	46	123	161	0	-59	40	-46	-108	-157	0	-10	5	25
91072112	3	15.6N	124.3E	50	0	102	213	225	-71	-53	14	-73	-207	-225	0	-5	0	40
91072118	4	16.1N	123.6E	55	8	78	143	125	-73	-33	32	-30	-140	-121	0	-5	0	45
91072200	5	16.7N	122.8E	65	13	98	104	77	-71	-22	22	-69	-102	-74	0	-10	10	25
91072206	6	17.6N	122.0E	70	21	119	101	95	-46	-18	50	-110	-100	-81	-5	-5	15	20
91072212	7	18.6N	121.1E	55	11	115	104		-26	12		-112	-104		10	10	45	
91072218	8	19.4N	119.9E	55	16	106	94		17	55		-106	-77		5	10	45	
91072300	9	20.1N	118.4E	60	41	115	116		8	58		-115	-102		0	5	25	
91072306	10	20.6N	116.7E	60	67	111	152		46	69		-101	-135		5	5	25	
91072312	11	21.1N	115.2E	65	20	156			-37			152			0	10		
91072318	12	21.6N	114.2E	65	24	58			-42			40			0	15		
91072400	13	22.0N	113.2E	65	6	33			-6			33			0	5		
91072406	14	22.3N	112.2E	55	0	24			24			6			0	10		
91072412	15	22.6N	111.4E	40	16										5			
91072418	16	23.0N	110.6E	30	12										5			
				Average	20	89	130	147	37	39	45	75	122	137	3	9	18	28
				# Cases	16	14	10	6	14	10	6	14	10	6	16	14	10	6

TYPHOON CAITLIN (09W)

DTG	WRN NO.	BEST TRACK LAT	LONG	WIND	POSITION ERRORS 00	24	48	72	X-TRACK 24	48	72	A-TRACK 24	48	72	WIND ERRORS 00	24	48	72
91072312	1	14.0N	132.9E	30	21	34	233	380	-35	-233	-356	0	1	-136	-5	-5	0	0
91072318	2	14.2N	131.9E	35	13	128	268	404	-121	-268	-306	-41	-18	-265	-10	0	5	-5
91072400	3	14.4N	131.0E	40	34	205	259	309	-196	-250	-246	-64	-70	-189	-5	-10	0	-5
91072406	4	14.8N	130.3E	45	46	227	283	341	-226	-263	-246	25	-105	-237	-5	-10	-5	-5
91072412	5	15.5N	130.2E	45	21	122	214	293	-110	-153	-194	-54	-151	-220	0	-10	-10	-5
91072418	6	16.4N	130.2E	45	36	139	219	292	-63	-39	-193	-125	-216	-220	0	-10	-15	-10
91072500	7	17.5N	130.2E	55	12	123	144	111	108	141	111	-60	31	7	0	10	10	0
91072506	8	18.5N	129.8E	60	18	116	133	115	111	118	115	-38	61	7	-5	5	10	-5
91072512	9	19.4N	129.1E	65	18	37	58	61	37	21	-57	4	54	24	0	5	5	-10
91072518	10	20.3N	128.4E	65	18	57	127	271	-50	-118	-175	-30	-47	-207	0	-5	-10	-10
91072600	11	21.3N	127.8E	70	6	56	70	143	-16	-69	-70	54	18	-126	0	-5	-5	-10
91072606	12	22.2N	127.4E	75	16	63	73	173	-22	-73	-26	60	-6	-172	-5	-5	-5	0
91072612	13	23.1N	127.0E	80	12	32	66	107	-21	-62	-12	24	-24	-107	-5	0	0	10

TYPHOON CAITLIN (09W) (CONTINUED)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91072618	14	23.8N	126.7E	85	13	27	71	137	-27	-32	-17	6	-64	-136	0	-5	-5	5
91072700	15	24.4N	126.6E	90	17	67	97	194	-64	-29	-30	-24	-93	-192	0	-10	-10	-5
91072706	16	25.2N	126.5E	90	26	91	139		-48	7		-78	-139		0	-20	-15	
91072712	17	26.1N	126.6E	90	0	36	82		5	0		-36	-82		0	-20	-15	
91072718	18	27.1N	126.7E	95	16	31	76		31	-5		2	-77		-5	-25	-20	
91072800	19	28.2N	126.9E	95	13	30	88		27	-73		13	-50		-5	-20	-20	
91072806	20	29.4N	127.1E	95	6	30			-27			-14			0	-10		
91072812	21	30.5N	127.2E	90	13	59			-54			-25			0	-10		
91072818	22	31.7N	127.5E	90	0	114			-73			-87			-10	-20		
91072900	23	33.0N	128.1E	85	42	214			-139			-163			-15	-25		
91072906	24	34.3N	129.1E	75	25										-10			
91072912	25	35.8N	130.5E	65	7										5			
91072918	26	37.4N	132.0E	65	17										0			
91073000	27	39.1N	133.4E	65	12										-10			
				Average	18	89	142	222	70	102	143	44	68	149	4	11	9	6
				# Cases	27	23	19	15	23	19	15	23	19	15	27	23	19	15

TROPICAL STORM ENRIQUE (06E) (NOTE: ONLY JTWC WARNINGS ARE VERIFIED.)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91080100	1	30.6N	175.4E	35	24	264			28			-263			0	20		
91080106	2	32.1N	173.4E	35	18										0			
91080112	3	34.2N	172.4E	30	5										0			
				Average	16	264			28			263			0	20		
				# Cases	3	1			1			1			3	1		

TROPICAL STORM DOUG (10W)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91080812	1	26.9N	161.5E	25	22	91			10			-91			0	-5		
91080900	2	28.1N	159.6E	30	37	198			-83			-180			-5	-10		
91080912	3	29.8N	158.3E	35	39	185			61			-176			0	25		
91080918	4	30.9N	157.4E	35	58	207			17			-207			0	15		
91081000	5	32.3N	156.5E	35	17	200			-81			-184			0	0		
91081006	6	33.9N	156.4E	35	23										0			
91081012	7	35.6N	156.8E	30	7										0			
91081018	8	37.4N	158.0E	30	25										0			
91081100	9	39.3N	159.6E	30	4										0			
				Average	26	176			50			167			0	11		
				# Cases	9	5			5			5			9	5		

TYPHOON ELLIE (11W)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91081018	1	23.9N	157.1E	40	30	97	206	534	96	166	312	18	-123	-435	-10	-15	-10	-30
91081100	2	24.2N	156.3E	45	29	55	261	606	55	206	373	-7	-161	-479	-5	0	-5	-25
91081106	3	24.5N	155.4E	45	13	51	293	661	35	203	420	-38	-212	-513	0	10	5	-20
91081112	4	24.8N	154.2E	45	27	97	118	97	-51	-74	-5	-83	-92	-97	5	10	5	0
91081118	5	25.2N	152.8E	50	50	24	67	162	-21	38	132	12	-56	-95	0	10	0	-5
91081200	6	25.8N	151.3E	50	27	88	141	205	-40	-1	82	-80	-141	-189	0	5	-5	0
91081206	7	26.3N	149.9E	50	30	119	218	251	49	107	164	-108	-191	-191	-5	0	-10	10
91081212	8	26.8N	148.4E	50	20	99	202	314	48	138	204	-87	-148	-239	-5	-5	-10	15
91081218	9	27.1N	147.0E	50	24	76	135	189	68	135	176	35	11	-71	-5	-20	-25	0

TYPHOON ELLIE (11W) (CONTINUED)

DTG	WRN NO.	BEST TRACK LAT	LONG	WIND	POSITION ERRORS 00	24	48	72	X-TRACK 24	48	72	A-TRACK 24	48	72	WIND ERRORS 00	24	48	72
91081300	10	27.3N	145.5E	55	44	81	113	114	74	96	112	34	61	-21	-10	-10	0	20
91081306	11	27.3N	144.2E	60	0	24	81	172	23	61	84	-10	-55	-150	-5	-5	10	30
91081312	12	27.2N	142.9E	65	20	80	149	220	73	108	111	-35	-103	-190	-5	0	25	50
91081318	13	27.0N	141.7E	70	24	81	176	236	66	99	114	-48	-146	-207	-5	-5	30	50
91081400	14	26.8N	140.6E	75	5	32	118	157	3	26	109	-33	-116	-113	0	10	35	55
91081406	15	26.6N	139.4E	80	10	76	155	181	23	55	151	-73	-146	-102	0	20	45	55
91081412	16	26.4N	138.2E	80	16	99	165	188	18	37	140	-98	-161	-126	0	15	40	50
91081418	17	26.2N	136.9E	85	20	72	154	180	13	58	144	-71	-143	-110	-10	0	5	10
91081500	18	26.1N	135.4E	85	29	129	194	181	-5	35	23	-130	-191	-180	-15	0	20	35
91081506	19	25.9N	133.9E	80	32	143	181	173	6	74	27	-144	-166	-171	-15	5	20	40
91081512	20	25.8N	132.2E	75	55	126	140	150	19	72	-29	-125	-121	-148	-10	15	25	35
91081518	21	25.7N	130.7E	70	29	108	153	164	67	29	164	86	151	7	-5	10	10	0
91081600	22	25.6N	129.1E	70	8	68	137	204	45	32	190	52	134	-74	-5	15	15	5
91081606	23	25.4N	127.7E	65	16	104	222		8	50		105	217		5	15	10	
91081612	24	25.2N	126.5E	60	5	27	93		-4	67		27	65		0	20	10	
91081618	25	25.0N	125.4E	60	27	109	193		-26	177		106	79		-5	0	10	
91081700	26	24.9N	124.3E	55	17	94			-13			93			-5	0		
91081706	27	24.9N	123.4E	55	16	52			-7			52			0	10		
91081712	28	25.0N	122.6E	50	5	5			-3			-4			0	10		
91081718	29	25.1N	121.8E	50	12	54			25			-48			0	10		
91081800	30	25.1N	121.0E	40	5	76			55			-54			10	15		
91081806	31	25.0N	120.2E	35	5	118			98			-67			10	5		
91081812	32	24.7N	119.5E	30	20										15			
91081818	33	24.2N	119.1E	30	54										5			
91081900	34	23.8N	118.8E	25	12										5			
				Average	22	80	163	243	36	85	148	63	127	177	5	9	11	25
				# Cases	34	31	25	22	31	25	22	31	25	22	34	31	25	22

TYPHOON FRED (12W)

DTG	WRN NO.	BEST TRACK LAT	LONG	WIND	POSITION ERRORS 00	24	48	72	X-TRACK 24	48	72	A-TRACK 24	48	72	WIND ERRORS 00	24	48	72
91081112	1	16.5N	123.7E	25	23	69	159	212	3	17	51	-70	-159	-206	0	30	30	20
91081118	2	17.0N	123.2E	25	5	18	47	49	15	45	34	11	-15	-36	0	20	15	15
91081200	3	17.3N	122.9E	25	18	36	66	84	35	55	74	11	37	43	0	15	10	10
91081206	4	17.7N	122.7E	25	37	61	82	127	61	49	73	-2	67	105	0	10	10	-5
91081212	5	18.1N	122.0E	25	23	131	125	129	41	66	75	-125	-107	-106	0	-5	0	-10
91081218	6	18.4N	121.2E	25	40	79	62	64	20	0	8	-77	-62	-64	0	-15	-5	-20
91081300	7	18.6N	120.4E	30	25	6	36	41	5	-36	-35	3	2	-22	-5	-15	-10	-35
91081306	8	18.7N	119.6E	30	16	21	68	74	-8	-60	-69	-20	-33	-28	0	-10	-10	-40
91081312	9	18.8N	119.0E	35	12	60	85	53	-57	-80	-53	-18	-32	-7	0	10	10	-25
91081318	10	18.9N	118.4E	45	8	72	113	69	-72	-112	-68	-7	-15	11	0	5	0	-10
91081400	11	19.1N	117.7E	50	6	8	56	103	-5	-17	15	-6	-54	-102	0	0	-5	-15
91081406	12	19.5N	117.1E	55	11	16	94	153	4	-15	93	-16	-94	-123	-5	-5	-5	-10
91081412	13	19.9N	116.4E	60	5	53	179	260	47	61	217	-26	-169	-143	0	5	-15	-10
91081418	14	20.0N	115.6E	65	5	76	181	288	12	26	171	-76	-179	-233	0	-5	-10	30
91081500	15	20.1N	114.7E	70	8	57	137	273	1	67	146	-58	-120	-232	-5	-10	-5	20
91081506	16	20.3N	113.8E	75	5	75	121		-18	79		-73	-93		0	5	5	
91081512	17	20.5N	112.7E	80	11	77	147		37	131		-68	-69		0	-10	-10	
91081518	18	20.4N	111.5E	90	25	102	152		76	143		-68	-52		0	-10	5	
91081600	19	20.2N	110.3E	95	5	120	166		120	131		12	-103		5	15	5	
91081606	20	19.9N	109.2E	95	18	135			135			12			0	-15		
91081612	21	19.4N	108.6E	90	26	122			122			-9			0	-25		
91081618	22	18.9N	107.9E	85	12	45			24			-39			5	-5		
91081700	23	18.5N	107.4E	80	20	71			-38			-60			0	5		
91081706	24	18.2N	106.7E	75	6										5			

TYPHOON FRED (12W) (CONTINUED)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91081712	25	17.9N	105.7E	55	23										20			
91081718	26	17.7N	104.2E	35	8										15			
91081800	27	17.4N	103.0E	25	36										5			
				Average	16	66	109	132	41	62	78	37	76	97	3	11	9	18
				# Cases	27	23	19	15	23	19	15	23	19	15	27	23	19	15

TROPICAL DEPRESSION 13W

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91081212	1	22.9N	155.8E	25	23	259			-141			-218			0	10		
91081218	2	24.1N	154.3E	25	26	234			-119			-202			0	10		
91081300	3	25.5N	152.7E	25	56										0			
91081306	4	27.2N	150.8E	25	44										0			
91081318	5	29.2N	145.6E	25	5										0			
				Average	31	246			130			210			0	10		
				# Cases	5	2			2			2			5	2		

TYPHOON GLADYS (14W)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91081600	1	22.3N	147.3E	25	0	58	86	94	-21	44	85	-54	-75	-41	0	5	10	20
91081606	2	22.9N	146.2E	30	30	51	103	144	42	94	126	-30	-44	-71	0	0	10	20
91081612	3	23.5N	145.1E	30	89	86	140	300	86	113	294	7	83	59	0	10	35	65
91081618	4	24.2N	144.1E	35	113	162	180	296	124	166	296	-105	-70	-24	0	10	40	70
91081700	5	25.1N	143.2E	40	21	64	194	288	-24	36	140	60	191	252	0	15	45	55
91081706	6	25.8N	142.3E	45	20	24	150	265	20	72	170	15	132	204	-5	15	45	50
91081712	7	26.2N	141.3E	45	43	109	174	252	8	35	48	109	171	248	5	15	45	50
91081718	8	26.5N	140.2E	50	55	189	299	308	5	38	40	189	298	306	0	20	45	50
91081800	9	26.8N	139.3E	50	24	107	197	271	4	26	100	108	196	252	5	20	45	50
91081806	10	27.1N	138.5E	50	18	68	143	212	-33	-3	-191	60	144	93	10	20	40	45
91081812	11	27.4N	137.8E	55	36	68	90	141	-45	-33	-141	52	85	8	5	15	25	25
91081818	12	27.6N	137.1E	55	22	37	66	114	37	60	-77	-5	30	85	5	15	25	30
91081900	13	27.7N	136.3E	55	41	60	78	101	58	73	-82	15	29	61	0	20	25	30
91081906	14	27.8N	135.5E	55	46	113	137	159	38	-103	-153	107	91	44	0	10	20	35
91081912	15	27.9N	134.8E	55	20	59	91	147	31	-78	-148	51	49	-4	0	10	15	30
91081918	16	28.0N	134.1E	55	59	121	173	181	0	-159	-167	121	68	70	0	10	15	20
91082000	17	28.1N	133.4E	55	15	21	84	97	6	-83	-98	-20	-17	0	0	15	20	30
91082006	18	28.2N	132.7E	60	15	51	87	54	-37	-87	-48	36	7	-25	0	10	25	30
91082012	19	28.3N	131.9E	60	15	26	101	134	-26	-57	-76	-6	-84	-110	0	10	30	35
91082018	20	28.5N	131.2E	60	21	93	202	123	-84	-192	-123	-41	-62	-9	0	10	25	35
91082100	21	28.7N	130.4E	60	13	102	177	143	-94	-165	-86	-41	-66	-115	0	15	30	40
91082106	22	29.0N	130.0E	65	12	126	185	225	-83	-186	-63	-95	-5	-217	0	25	35	45
91082112	23	29.4N	129.8E	65	18	132	162		-57	-120		-120	-66		0	30	40	
91082118	24	29.9N	129.6E	60	36	126	161		-99	-123		-79	-105		5	30	45	
91082200	25	30.5N	129.4E	55	36	84	115		-82	-44		-23	-106		5	25	30	
91082206	26	31.2N	129.3E	50	35	72	167		-63	6		-37	-168		5	15	25	
91082212	27	32.0N	129.2E	45	11	84			-3			-85			5	10		
91082218	28	32.9N	128.9E	45	31	65			9			-64			0	5		
91082300	29	33.8N	128.4E	40	11	153			105			-113			5	5		
91082306	30	34.4N	127.6E	40	46	219			168			-140			0	5		
91082312	31	34.7N	126.5E	35	12										-5			
				Average	31	91	144	184	49	85	125	66	93	104	2	14	30	39
				# Cases	31	30	26	22	30	26	22	30	26	22	31	30	26	22

TROPICAL DEPRESSION 15W

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91082606	1	27.4N	137.0E	30	16	53			14			-51			0	0		
91082618	2	27.9N	135.3E	30	81	159			-88			-132			-5	0		
91082700	3	28.0N	134.5E	30	17	59	186		-9	-10		-59	-186		0	0	10	
91082706	4	28.2N	133.5E	30	12	92	310		-57	8		-73	-310		0	0	15	
91082712	5	28.7N	132.7E	30	36	175	404		-54	77		-167	-397		0	5	20	
91082718	6	29.3N	131.8E	30	5	79			-15			-78			0	10		
91082800	7	30.0N	130.7E	30	5	35			-35			0			0	20		
91082806	8	30.7N	129.6E	30	6	72			-31			-66			0	20		
91082812	9	31.6N	128.9E	30	12	73			-44			-59			0	15		
91082818	10	32.5N	128.6E	30	5										0			
91082900	11	33.5N	128.7E	25	15										0			
				Average	19	88	300		38	31		76	297		0	8	15	
				# Cases	11	9	3		9	3		9	3		11	9	3	

TROPICAL STORM HARRY (16W)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91082906	1	26.0N	133.5E	25	34	104	359		-74	23		-73	-359		0	-5	5	
91082912	2	27.1N	133.8E	25	42	163	468		-99	37		-130	-467		5	0	5	
91082918	3	28.3N	134.3E	30	12	104			-12			-104			0	0		
91083000	4	29.7N	134.9E	35	5	117			15			-117			-5	0		
91083006	5	31.2N	135.7E	40	31	228			37			-226			-5	0		
91083012	6	32.9N	136.7E	40	7	152			-7			-152			-5	0		
91083018	7	34.7N	138.1E	40	25										5			
91083100	8	36.5N	140.0E	40	26										5			
91083106	9	38.4N	142.6E	40	42										0			
91083112	10	40.2N	146.2E	40	29										0			
				Average	25	145	413		40	30		133	413		3	1	5	
				# Cases	10	6	2		6	2		6	2		10	6	2	

TYPHOON IVY (17W)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91090212	1	8.4N	154.5E	30	41	156	216	400	-99	-216	-388	121	3	-100	-5	-5	10	20
91090218	2	9.0N	154.0E	30	51	116	217	436	-91	-213	-417	73	-44	-128	0	5	15	25
91090300	3	9.5N	153.4E	35	25	17	157	390	-16	-110	-308	-8	-112	-241	0	5	10	15
91090306	4	9.9N	152.7E	35	12	24	209	502	17	-170	-440	-17	-121	-242	0	10	10	15
91090312	5	10.4N	151.9E	40	13	61	257	533	6	-168	-454	-61	-195	-280	0	10	10	15
91090318	6	10.9N	150.9E	40	21	85	345	594	-47	-264	-453	-72	-224	-386	0	10	10	20
91090400	7	11.4N	149.9E	45	5	175	425	602	-152	-380	-511	-88	-191	-320	0	0	5	10
91090406	8	12.1N	149.0E	45	18	225	463	590	-204	-428	-427	-95	-179	-409	0	-5	-5	0
91090412	9	13.0N	148.6E	50	36	258	490	654	-200	-418	-371	-164	-258	-541	0	-10	-10	0
91090418	10	13.9N	148.2E	55	56	306	462	542	-231	-330	-245	-201	-324	-485	0	-5	-5	5
91090500	11	15.0N	147.9E	65	36	153	273	294	-55	-43	104	-144	-270	-275	0	0	-10	-5
91090506	12	16.1N	147.5E	65	42	209	343	338	-71	42	120	-197	-340	-317	5	-5	-25	-15
91090512	13	17.5N	147.0E	70	17	155	239	230	-19	34	180	-154	-237	-144	0	-10	-25	-10
91090518	14	19.1N	146.2E	75	32	150	171	126	18	12	58	-150	-171	-113	-5	-20	-30	-15
91090600	15	20.6N	145.2E	85	28	136	113	60	51	105	-50	-127	-41	-33	-5	-20	-15	-5
91090606	16	22.0N	144.0E	90	22	73	179	277	74	76	-183	-5	163	209	-10	-25	-15	-10
91090612	17	23.1N	142.4E	95	17	113	174	288	-11	-105	-288	113	139	4	0	-10	0	-10
91090618	18	24.3N	141.1E	100	8	87	155	318	-12	-136	-307	87	76	-83	-5	-10	-15	-15
91090700	19	25.3N	139.9E	110	8	42	174	261	-42	-154	-259	6	82	35	-5	5	-5	-10
91090706	20	26.3N	139.0E	115	0	47	172		-47	-172		6	14		0	10	0	
91090712	21	27.3N	138.3E	115	8	70	221		-69	-206		18	-81		0	5	0	

TYPHOON IVY (17W) (CONTINUED)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91090718	22	28.2N	137.6E	115	7	112	275		-105	-224		-39	-161		0	-5	-5	
91090800	23	29.2N	137.5E	110	12	128	261		-127	-250		-18	-74		0	-5	-10	
91090806	24	30.2N	137.6E	105	13	141	274		-131	-251		-53	-111		0	5	-5	
91090812	25	31.1N	138.2E	105	6	115			-91			-70			0	15		
91090818	26	32.0N	139.1E	105	0	179			-120			-134			0	15		
91090900	27	32.9N	140.6E	95	11	112			-100			-50			5	-5		
91090906	28	33.7N	142.5E	80	5	44			-42			-13			0	0		
91090912	29	34.6N	145.2E	70	9										5			
91090918	30	35.6N	148.4E	65	12										10			
91091000	31	36.9N	151.9E	60	7										5			
91091006	32	38.4N	155.4E	55	6										5			
				Average	18	125	261	391	80	187	292	81	150	228	2	8	10	12
				# Cases	32	28	24	19	28	24	19	28	24	19	32	28	24	19

TROPICAL STORM JOEL (18W)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91090318	1	19.4N	117.9E	30	16	64	55	212	-6	-26	-207	-64	-49	-45	0	10	15	15
91090400	2	19.6N	117.1E	30	18	26	155	279	11	-146	-278	-24	-53	-30	0	5	10	30
91090406	3	19.8N	116.3E	30	28	0	169	309	0	-152	-281	0	-77	-129	0	10	15	50
91090412	4	20.0N	115.7E	30	8	101	298	439	-101	-280	-347	7	-104	-269	5	5	0	35
91090418	5	20.1N	115.1E	30	17	196	341		-155	-336		-121	56		5	5	10	
91090500	6	20.3N	114.8E	35	57	173	289		-173	-277		20	82		5	0	-10	
91090506	7	20.3N	114.8E	35	28	120	219		-101	-207		-65	-73		5	10	10	
91090512	8	20.5N	114.8E	40	21	143	313		-101	-151		-101	-275		0	-5	30	
91090518	9	20.9N	115.2E	40	37	154			-120			-97			0	10		
91090600	10	21.4N	115.4E	45	8	10			-10			5			-5	5		
91090606	11	22.0N	115.4E	50	18	76			35			-69			-5	10		
91090612	12	22.6N	115.3E	55	11	131			55			-120			-5	5		
91090618	13	23.1N	115.0E	40	5										0			
91090700	14	23.6N	114.7E	35	0										5			
91090706	15	24.5N	114.3E	30	17										0			
				Average	19	100	230	310	72	196	278	57	96	118	3	7	13	33
				# Cases	15	12	8	4	12	8	4	12	8	4	15	12	8	4

TYPHOON KINNA (19W)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91091012	1	17.0N	139.1E	25	42	197	242	442	-44	-62	2	-192	-235	-442	0	-10	-30	-25
91091018	2	18.2N	137.8E	30	13	173	142	419	90	120	-48	-149	-77	-417	-5	-15	-40	-20
91091100	3	19.3N	136.0E	35	16	110	122	249	9	76	72	-110	-96	-239	-5	-10	-25	5
91091106	4	20.3N	134.4E	40	12	96	181	508	-69	-41	77	-67	-177	-502	-5	-15	-20	20
91091112	5	21.2N	132.8E	45	24	98	234	694	-53	-56	129	-83	-228	-683	0	-10	-5	40
91091118	6	22.1N	131.4E	50	23	26	188		11	-59		24	-179		0	-10	0	
91091200	7	23.0N	130.2E	55	8	24	91		-5	29		24	-86		0	-10	-5	
91091206	8	23.9N	129.3E	65	8	24	194		-19	43		-15	-190		0	-5	0	
91091212	9	24.7N	128.4E	75	26	43	129		21	-2		38	-130		0	-5	10	
91091218	10	25.6N	127.9E	85	0	138			2			-138			0	5		
91091300	11	26.8N	127.8E	90	5	120			45			-112			0	10		
91091306	12	28.3N	128.0E	90	7	145			40			-140			0	10		
91091312	13	30.0N	128.5E	90	10	135			35			-131			0	10		
91091318	14	31.9N	129.4E	85	11										5			
91091400	15	34.2N	131.3E	75	23										0			
91091406	16	36.1N	134.3E	65	49										0			

TYPHOON KINNA (19W)(CONTINUED)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91091412	17	37.4N	138.4E	55	36										0			
				Average	18	102	169	462	34	54	65	94	155	456	1	10	15	22
				# Cases	17	13	9	5	13	9	5	13	9	5	17	13	9	5

TROPICAL STORM LUKE (20W)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91091418	1	16.8N	140.7E	30	8	33	119	114	-1	29	-11	-34	-115	-114	0	0	15	30
91091500	2	17.2N	139.5E	30	74	118	135	222	-76	-111	-207	92	-77	-81	0	10	25	35
91091506	3	17.7N	138.4E	35	80	71	169	306	-31	-22	-34	-65	-168	-304	0	5	20	35
91091512	4	18.2N	137.2E	35	38	101	126	327	32	-11	124	-97	-126	-303	0	5	20	35
91091518	5	18.8N	136.1E	40	29	122	104	198	42	22	59	-115	-102	-189	0	5	15	35
91091600	6	19.5N	134.9E	40	34	98	121	293	39	-22	-154	-90	-120	-250	0	5	15	35
91091606	7	20.4N	133.8E	45	45	24	26	240	22	23	-225	12	13	-85	-5	0	15	35
91091612	8	21.3N	132.5E	45	40	52	66	234	38	-64	-128	36	14	-196	0	10	25	35
91091618	9	22.4N	131.7E	45	21	72	156		-54	-144		48	-62		0	15	35	
91091700	10	23.3N	131.3E	45	102	286	590		-183	-267		-220	-527		0	-5	10	
91091706	11	24.0N	131.2E	50	196	385	723		-43	-458		-384	-562		0	5	20	
91091712	12	24.6N	131.0E	50	209	349	860		166	-407		-308	-761		0	10	30	
91091718	13	25.3N	130.8E	50	231	392			102			-380			0	15		
91091800	14	26.0N	130.6E	50	30	166			-152			-67			-5	-10		
91091806	15	26.9N	130.7E	50	30	229			-206			-103			-5	-10		
91091812	16	27.3N	132.1E	50	70	403			-236			-327			-5	-10		
91091818	17	27.6N	134.1E	45	155										0			
91091900	18	28.5N	137.0E	45	39										0			
91091906	19	31.6N	139.0E	45	31										0			
91091912	20	35.3N	141.6E	45	0										0			
				Average	73	181	266	242	88	131	117	148	220	190	1	8	20	34
				# Cases	20	16	12	8	16	12	8	16	12	8	20	16	12	8

SUPER TYPHOON MIREILLE (21W)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91091600	1	14.4N	158.8E	45	29	153	177	202	-112	16	54	106	176	195	-15	-25	-5	0
91091606	2	14.7N	157.6E	55	18	63	143	126	-29	87	63	57	114	110	-10	0	10	0
91091612	3	15.0N	156.7E	65	21	42	70	16	-23	20	11	35	68	12	-15	10	10	10
91091618	4	15.4N	155.9E	75	8	18	18	87	-19	19	10	-1	4	-87	-5	15	10	5
91091700	5	15.7N	155.1E	75	0	24	69	199	21	65	38	-12	-25	-196	0	15	10	5
91091706	6	16.0N	154.3E	75	29	143	223	343	139	219	303	34	49	-162	0	20	10	5
91091712	7	16.1N	153.6E	70	18	105	184	353	105	183	289	17	-26	-204	0	10	10	5
91091718	8	16.0N	152.9E	70	12	84	236	412	40	86	162	-74	-220	-379	0	5	5	5
91091800	9	15.8N	152.2E	70	13	39	141	198	-19	-40	45	-34	-135	-194	0	5	5	0
91091806	10	15.6N	151.6E	70	5	69	174	232	0	-23	108	-70	-173	-206	-5	5	5	-5
91091812	11	15.5N	150.8E	75	18	136	237	265	-19	-25	179	-135	-237	-196	0	10	5	-10
91091818	12	15.4N	149.9E	80	18	160	258	283	-39	-11	221	-156	-258	-177	0	5	5	-20
91091900	13	15.3N	148.8E	80	6	87	218	314	2	168	312	-88	-141	36	0	5	0	-25
91091906	14	15.4N	147.5E	80	0	68	314	461	61	314	438	-31	-15	144	0	5	-10	-50
91091912	15	15.5N	146.2E	80	8	145	374	576	138	374	507	-47	20	275	0	-10	-35	-75
91091918	16	15.5N	144.7E	85	6	192	408	574	186	378	440	-46	154	370	-5	-15	-50	-70
91092000	17	15.4N	143.2E	85	13	103	273	465	101	257	385	-22	95	261	-5	-10	-35	-50
91092006	18	15.1N	141.9E	85	11	85	242	391	75	170	233	41	173	316	0	-10	-35	-40
91092012	19	14.9N	140.5E	85	6	48	181	324	46	117	229	13	138	229	5	-10	-40	-50
91092018	20	14.6N	139.3E	85	11	71	207	386	14	111	350	70	176	163	0	-20	-40	-50
91092100	21	14.5N	138.2E	90	5	62	154	273	-50	-53	166	38	145	218	0	-25	-25	-25

SUPER TYPHOON MIREILLE (21W) (CONTINUED)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91092106	22	14.5N	137.2E	95	8	45	110	260	-45	-47	147	-6	100	216	5	-25	-25	-25
91092112	23	14.7N	136.2E	100	0	11	34	186	-9	-25	111	-8	23	149	0	-30	-25	-25
91092118	24	15.0N	135.3E	110	8	46	98	228	-29	70	186	36	69	133	0	-10	-20	-20
91092200	25	15.4N	134.5E	115	8	40	102	236	-26	74	177	31	70	157	0	0	-5	-5
91092206	26	15.8N	133.8E	125	8	36	114	254	-17	81	159	32	80	199	5	0	-5	0
91092212	27	16.3N	133.1E	130	5	23	114	240	-12	79	159	20	83	180	0	0	-5	5
91092218	28	16.9N	132.5E	130	12	75	169	249	68	168	229	-31	24	99	0	0	0	5
91092300	29	17.5N	131.9E	130	20	103	208	263	100	192	148	25	81	218	0	0	0	5
91092306	30	18.0N	131.4E	130	8	96	192	222	86	165	121	44	99	187	0	0	5	5
91092312	31	18.7N	130.9E	130	17	77	166	245	67	134	125	39	99	211	-5	-10	5	5
91092318	32	19.1N	130.2E	130	8	55	128	121	35	114	0	43	61	121	-5	-5	5	10
91092400	33	19.5N	129.6E	130	0	17	48	69	-9	-5	-51	15	48	47	-5	-5	-5	0
91092406	34	19.9N	129.2E	130	11	29	84	83	-2	-5	-84	29	84	-8	-5	0	-10	0
91092412	35	20.5N	128.8E	130	6	92	220	139	24	42	-118	90	216	-75	-5	5	-15	5
91092418	36	20.9N	128.2E	125	11	84	145	336	52	-30	-134	66	142	-308	0	5	-10	15
91092500	37	21.5N	127.6E	125	5	40	42		27	-21		-30	36		0	5	-10	
91092506	38	22.2N	127.1E	120	5	32	117		27	-27		-18	-114		0	-15	-15	
91092512	39	23.0N	126.7E	115	12	81	160		69	-7		42	-160		0	-15	-5	
91092518	40	23.7N	126.1E	115	5	13	445		0	0		-13	-446		0	-10	5	
91092600	41	24.4N	125.8E	115	6	173			-51			-166			0	0		
91092606	42	25.4N	125.7E	115	8	198			-60			-190			0	0		
91092612	43	26.5N	125.9E	115	6	281			-3			-281			0	10		
91092618	44	28.1N	126.4E	110	13	314			-23			-314			0	10		
91092700	45	30.0N	127.6E	100	0										0			
91092706	46	32.3N	129.2E	95	18										0			
91092712	47	35.3N	132.5E	85	11										0			
91092718	48	38.5N	137.0E	75	33										0			
				Average	10	88	175	267	47	100	180	61	114	178	2	9	13	18
				# Cases	48	44	40	36	44	40	36	44	40	36	48	44	40	36

TYPHOON NAT (22W)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91091600	1	20.5N	121.3E	25	73	102			82			62			0	-15		
91091606	2	20.6N	120.4E	30	52	98	127	153	-50	-127	-70	-84	-10	-137	0	-5	0	10
91091612	3	20.6N	119.6E	35	18	46	159	295	39	-79	-56	-24	-138	-290	0	5	0	10
91091618	4	20.5N	119.0E	40	57	154	299	480	146	-136	-106	-49	-267	-469	-5	5	0	10
91091700	5	20.3N	118.6E	40	28	130	293	489	-49	-112	-98	-121	-271	-480	-5	5	0	5
91091706	6	20.0N	118.4E	40	38	134	254	371	-82	-57	-25	-107	-248	-370	-5	0	5	0
91091712	7	19.7N	118.5E	35	51	141	242	304	-61	-21	-18	-127	-242	-304	5	0	5	-5
91091718	8	19.5N	118.7E	35	68	158	261	304	-51	-15	-27	-150	-261	-303	0	0	5	-10
91091800	9	19.4N	119.1E	35	32	80	186	242	-9	19	4	-80	-185	-242	0	0	0	-20
91091806	10	19.5N	119.6E	40	40	122	221	267	11	40	20	-122	-218	-266	-5	0	-5	-30
91091812	11	19.7N	120.1E	40	16	61	122	253	53	81	22	31	92	-252	-5	5	-10	-45
91091818	12	19.9N	120.6E	40	17	45	119	296	45	77	24	4	91	-295	-5	5	-15	-55
91091900	13	20.1N	121.2E	40	12	37	89	329	32	57	87	-20	69	-318	-5	5	-15	-60
91091906	14	20.3N	121.8E	35	69	180	312	585	-149	-168	397	102	264	-432	0	-5	-20	-45
91091912	15	20.5N	122.5E	35	12	44	186	469	-18	105	180	41	-155	-433	5	-10	-35	-50
91091918	16	20.7N	123.2E	35	30	29	147	461	-28	63	161	-7	-133	-433	5	-15	-45	-45
91092000	17	20.9N	123.8E	40	33	32	145	362	-24	-38	82	21	-140	-353	0	-15	-50	-40
91092006	18	21.0N	124.3E	45	32	69	256	479	6	49	155	69	-252	-454	-5	-20	-50	-20
91092012	19	21.1N	124.7E	50	17	76	255	445	-10	-17	96	-76	-255	-435	-10	-35	-50	0
91092018	20	21.2N	125.0E	55	24	60	233	377	30	49	33	-53	-229	-376	-10	-45	-45	10
91092100	21	21.3N	125.3E	60	8	87	266	354	-8	0	-111	-87	-267	-337	-5	-30	-30	20
91092106	22	21.4N	125.6E	70	8	121	296	353	-27	31	-190	-119	-295	-298	-5	-15	10	50

TYPHOON NAT (22W) (CONTINUED)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91092112	23	21.5N	125.2E	85	17	176	362	463	-15	64	-435	-176	-357	-160	0	-5	40	65
91092118	24	21.5N	124.7E	95	6	61	95	98	-25	-32	69	-92	-93	-96	-5	0	50	65
91092200	25	21.6N	124.1E	105	0	80	141	253	-16	-77	-241	-79	-119	-81	-15	0	55	65
91092206	26	21.7N	123.5E	110	12	62	129	253	12	-77	-206	-61	-104	-146	0	10	50	55
91092212	27	21.8N	122.6E	110	8	83	154	253	-9	-150	-219	-83	-39	-129	0	35	55	55
91092218	28	21.9N	121.6E	105	16	49	121	255	-32	-82	-168	-37	-89	-194	5	15	30	45
91092300	29	22.1N	120.7E	105	0	53	147	278	-43	-112	-173	-31	-97	-218	10	45	50	50
91092306	30	22.3N	120.0E	90	8	45	235	358	11	-105	-139	-44	-211	-331	10	35	35	40
91092312	31	22.5N	119.5E	70	26	126	306	433	-29	-104	-77	-124	-289	-426	5	5	5	5
91092318	32	22.6N	119.0E	60	6	94	261	394	-34	-162	-390	-88	-206	-56	10	5	5	5
91092400	33	22.6N	118.6E	55	12	159	378	605	-111	-284	-555	-115	-251	242	-5	-5	0	0
91092406	34	22.5N	118.1E	50	8	189	420	588	-123	-295	409	-145	-299	424	0	-5	0	0
91092412	35	22.0N	117.6E	45	8	122	311	403	22	-118	201	-120	-289	350	0	-5	0	0
91092418	36	20.9N	117.1E	45	24	72	228	287	-11	-212	146	-72	-85	247	0	-5	0	0
91092500	37	19.9N	116.8E	45	23	164	241	240	-148	-230	182	-73	74	158	-10	-5	0	-5
91092506	38	19.2N	116.6E	45	18	140	175	188	-102	68	114	-97	162	151	-10	-5	0	-10
91092512	39	18.8N	116.4E	40	18	142	125	178	-132	97	107	-55	78	-143	-5	5	10	5
91092518	40	18.2N	116.1E	40	37	46	60	88	30	-58	80	-35	18	36	-5	5	10	0
91092600	41	17.6N	116.0E	35	94	136			-22			135			-5	0		
91092612	42	16.3N	116.2E	30	34	49			12			48			0	0		
91092700	43	15.7N	117.0E	30	16	36			35			12			0	-5		
91092712	44	15.9N	117.5E	30	49	40			-4			40			0	-10		
91092800	45	16.3N	117.5E	35	46	30	122	283	6	8	-131	-30	-123	-251	0	-15	-15	-15
91092806	46	16.4N	117.3E	40	8	34	106	259	34	-57	-125	6	-90	-227	-5	-5	-10	-5
91092812	47	16.5N	116.9E	40	31	67	132	241	63	6	-28	-24	-132	-240	0	0	5	5
91092818	48	16.6N	116.6E	45	42	92	233	337	23	-51	-152	-90	-228	-301	-5	0	0	15
91092900	49	16.9N	116.5E	50	43	139	294	405	16	-86	-195	-139	-282	-356	0	5	5	40
91092906	50	17.2N	116.5E	50	49	160	275	363	-57	-80	-316	-150	-264	-180	0	0	0	50
91092912	51	17.5N	116.5E	55	31	161	293		-108	-130		-119	-263		0	0	0	
91092918	52	18.2N	116.6E	55	17	118	172		-118	-172		-11	-13		5	10	20	
91093000	53	18.9N	117.0E	55	22	58	151		-50	-130		-30	-78		5	10	20	
91093006	54	19.6N	117.3E	60	20	122	173		-121	-170		19	36		0	0	15	
91093012	55	20.4N	117.5E	60	24	89			82			36			0	-5		
91093018	56	21.3N	117.7E	60	26	141			140			-17			0	5		
91100100	57	22.1N	117.6E	60	13	118			-9			-118			0	35		
91100106	58	22.8N	117.5E	65	8	131			-61			-117			0	45		
91100112	59	23.6N	117.3E	65	26										0			
91100118	60	24.2N	117.0E	50	20										5			
91100200	61	25.0N	116.7E	35	12										0			
				Average	26	96	210	337	49	92	150	72	172	275	4	10	18	25
				# Cases	61	58	49	45	58	49	45	58	49	45	61	58	49	45

TYPHOON ORCHID (23W)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91100400	1	19.1N	139.0E	35	41	116	180	280	111	173	180	33	50	215	-5	15	10	-30
91100406	2	19.1N	137.3E	40	22	144	194	265	31	66	-121	141	183	237	-10	10	0	-35
91100412	3	19.1N	137.3E	40	34	130	180	297	2	6	-292	-130	180	59	-5	5	-10	-25
91100418	4	19.1N	136.7E	45	20	41	75	191	-25	28	-191	33	70	14	0	10	-15	-25
91100500	5	19.2N	136.2E	50	20	64	71	94	8	71	-61	-64	-11	72	0	5	-25	-25
91100506	6	19.2N	135.7E	55	16	90	120	110	76	118	-77	-49	24	78	0	-5	-25	-15
91100512	7	19.2N	135.1E	60	24	96	134	193	81	-61	-176	52	120	80	0	-10	-20	-15
91100518	8	19.1N	134.3E	65	12	34	129	287	-1	-129	-216	35	7	-190	-5	-20	-20	-10
91100600	9	19.0N	133.6E	70	12	23	118	331	-4	-118	-260	23	13	-206	-5	-25	-15	0
91100606	10	18.9N	133.0E	80	13	30	124	359	-4	-123	-223	30	-17	-283	-5	-15	10	20

TYPHOON ORCHID (23W)(CONTINUED)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91100612	11	19.0N	132.4E	90	12	50	177	429	-51	-173	-255	0	-40	-345	0	10	20	30
91100618	12	19.1N	131.9E	100	5	71	212	408	-62	-135	-211	-36	-164	-350	0	15	15	25
91100700	13	19.3N	131.4E	110	11	86	269	442	-62	-122	-237	-60	-241	-374	5	20	30	45
91100706	14	19.5N	131.0E	115	13	111	317	459	-73	-122	-256	-84	-293	-382	5	25	35	45
91100712	15	19.8N	130.7E	110	6	55	232	331	-50	-105	-254	-24	-208	-213	5	15	25	30
91100718	16	20.3N	130.6E	110	11	78	193	173	-60	-139	-140	-50	-135	104	5	15	20	15
01100800	17	20.8N	130.4E	110	0	92	144	189	-46	-110	35	-80	-94	186	0	10	25	25
91100806	18	21.4N	130.5E	105	5	119	145	188	-60	-118	55	-103	-85	180	5	15	25	20
91100812	19	22.2N	130.7E	105	20	142	135	121	-43	-94	8	-136	-98	122	0	0	5	5
91100818	20	23.1N	131.1E	100	26	68	31	209	-4	-10	7	-68	30	210	0	5	5	5
91100900	21	24.1N	131.8E	100	8	55	208	448	-31	143	-48	45	152	446	0	10	10	5
91100906	22	25.0N	132.5E	95	0	112	330	546	-29	240	-145	108	228	527	-5	-5	-5	-15
91100912	23	25.8N	133.2E	90	5	71	276	535	24	144	-25	67	236	535	-5	-10	-10	-5
91100918	24	26.5N	134.1E	85	8	55	225		52	65		18	216		-5	-10	-10	
91101000	25	27.1N	134.8E	80	13	52	201		52	-10		0	201		0	-10	-10	
91101006	26	27.7N	135.5E	80	10	52	78		52	25		-6	74		-5	-10	-10	
91101012	27	28.2N	136.0E	75	7	82	84		65	13		52	84		0	-5	-5	
91101018	28	28.8N	136.4E	75	5	99	242		48	-16		87	242		-5	-5	-5	
91101100	29	29.4N	136.6E	70	15	70	16		-16	-3		69	-16		-5	-5	-5	
91101106	30	30.0N	136.8E	70	15	141			-85			113			-5	-5		
91101112	31	30.5N	137.1E	65	19	61			-62			-4			-10	-5		
91101118	32	30.9N	137.6E	65	11	87			-87			8			-10	-5		
91101200	33	31.3N	138.2E	60	5	20			-6			-20			-10	-5		
91101206	34	31.7N	138.9E	60	16										-10			
91101212	35	32.1N	139.8E	55	19										-5			
91101218	36	32.7N	141.0E	55	23										-10			
91101300	37	33.6N	142.7E	55	19										-10			
				Average	14	79	167	299	44	92	151	55	121	235	4	10	15	20
				# Cases	37	33	29	23	33	29	23	33	29	23	37	33	29	23

TYPHOON PAT (24W)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91100512	1	15.3N	156.7E	35	16	34	93	249	24	-92	-229	-24	-18	-100	-10	-15	-45	-60
91100518	2	15.4N	155.6E	40	29	69	199	357	-47	-195	-332	51	-40	-133	-15	-20	-60	-55
91100600	3	15.4N	154.6E	45	5	102	247	369	-98	-241	-366	-30	-57	50	-10	-20	-45	-15
91100606	4	15.6N	153.5E	50	6	116	280	386	-115	-275	-378	-17	-57	-79	-15	-25	-45	-10
91100612	5	15.7N	152.6E	55	8	160	359	477	-161	-359	-455	1	-30	146	-10	-35	-40	0
91100618	6	16.0N	152.1E	60	18	137	305	407	-137	-301	-399	-5	-50	-81	-10	-35	-25	10
91100700	7	16.2N	151.9E	70	21	140	256	353	-121	-256	-316	-71	-11	-157	-10	-35	-10	10
91100706	8	16.5N	151.6E	80	18	127	226	331	-109	-226	-303	-65	-11	-133	-10	-30	-5	15
91100712	9	16.9N	151.4E	95	20	112	190	309	-108	-190	-290	-29	16	-109	-5	-10	15	25
91100718	10	17.4N	151.2E	110	11	67	112	225	-68	-112	-201	0	-11	-101	-5	0	20	30
91100800	11	17.9N	151.2E	120	5	32	48	137	-23	-6	-58	-22	-48	-125	0	20	35	45
91100806	12	18.4N	151.2E	125	11	71	58	148	6	22	-40	-72	-54	-143	-5	0	5	15
91100812	13	19.0N	151.1E	125	0	17	27	195	12	-28	-177	-13	0	-82	-5	5	10	15
91100818	14	19.6N	150.9E	120	0	8	76	262	6	-68	-214	6	35	-153	-5	5	10	20
91100900	15	20.2N	150.6E	115	5	8	102	329	6	-81	-224	6	63	-242	0	5	15	25
91100906	16	20.8N	150.3E	110	5	24	147	386	-6	-128	-190	24	73	-337	0	5	15	20
91100912	17	21.3N	150.0E	105	0	44	168	362	-44	-150	-20	-6	-76	-362	0	5	10	15
91100918	18	21.8N	149.8E	100	5	83	194	459	-71	-149	-13	-43	-124	-460	0	5	10	15
91101000	19	22.3N	149.7E	100	12	104	317	693	-69	-161	-32	-78	-274	-693	0	10	15	15
91101006	20	22.8N	149.7E	95	12	109	235		-95	-96		-54	-216		0	10	10	
91101012	21	23.5N	149.9E	90	8	93	261		-80	-21		-48	-261		0	10	15	

TYPHOON PAT (24W) (CONTINUED)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91101018	22	24.2N	150.2E	85	12	93	210		-42	-5		-84	-211		0	5	10	
91101100	23	25.1N	150.6E	80	24	133	227		21	39		-132	-224		0	0	0	
91101106	24	26.3N	151.2E	75	5	190			180			61			0	0		
91101112	25	27.7N	151.5E	75	8	104			30			100			-5	0		
91101118	26	29.5N	151.5E	70	0	120			-44			112			0	5		
91101200	27	31.5N	151.6E	65	13	146			-109			98			0	5		
91101206	28	33.7N	152.0E	65	0										0			
91101212	29	35.8N	152.8E	60	7										0			
91101218	30	38.0N	153.9E	55	24										5			
91101300	31	40.3N	155.4E	55	27										-5			
				Average	11	90	189	339	67	139	223	46	85	194	4	12	20	22
				# Cases	31	27	23	19	27	23	19	27	23	19	31	27	23	19

SUPER TYPHOON RUTH (25W)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91102018	1	10.4N	143.5E	30	104	122	130	227	119	90	152	-30	-95	-169	-5	-10	-30	-70
91102100	2	10.9N	143.1E	35	75	11	21	70	9	-15	53	-7	-15	-47	-5	-10	-30	-40
91102106	3	11.3N	142.7E	40	48	66	47	79	-39	14	80	54	45	5	-5	-10	-40	-35
91102112	4	11.7N	142.4E	45	18	81	41	34	-77	-33	26	27	26	-22	-5	-10	-45	-30
91102118	5	12.0N	142.0E	50	5	78	34	60	-78	-28	35	-10	-21	-50	-5	-15	-50	-20
91102200	6	12.4N	141.6E	55	26	71	59	106	-70	-6	17	-16	-59	-105	0	-15	-25	-10
91102206	7	12.9N	141.2E	60	29	47	112	128	-14	54	12	-45	-99	-128	0	-20	-25	-10
91102212	8	13.4N	140.7E	70	0	59	70	46	51	61	29	-30	-35	-37	-5	-25	-20	-10
91102218	9	13.8N	139.9E	80	8	116	120	68	92	106	35	-71	-57	-59	-10	-25	-10	-5
91102300	10	14.0N	139.0E	95	5	41	60	66	2	-38	-64	41	47	17	-15	-25	-10	-10
91102306	11	14.2N	138.1E	110	5	25	43	50	12	34	-49	22	28	14	-15	-20	-10	-5
91102312	12	14.3N	137.2E	125	6	25	29	70	12	12	-65	22	27	27	-10	-10	-10	-5
91102318	13	14.4N	136.3E	135	5	26	11	55	18	-6	-54	-18	10	13	-10	-5	-5	0
91102400	14	14.5N	135.3E	140	8	17	40	120	7	14	-41	-16	-38	-114	-5	5	-5	0
91102406	15	14.7N	134.3E	145	8	34	70	110	-20	-29	7	-28	-64	-110	-5	5	0	5
91102412	16	15.0N	133.3E	145	8	26	72	165	-15	-2	67	-22	-73	-151	-5	10	5	10
91102418	17	15.3N	132.3E	140	0	54	120	214	-3	20	73	-55	-119	-202	0	10	5	25
91102500	18	15.7N	131.3E	140	0	12	120	325	0	32	279	-13	-116	-168	0	0	10	40
91102506	19	16.0N	130.3E	140	5	16	206	533	-8	74	512	-15	-193	-148	0	5	15	45
91102512	20	16.5N	129.4E	135	6	51	251	584	21	129	578	-47	-216	88	0	5	20	50
91102518	21	17.0N	128.5E	130	8	92	331	673	60	149	411	-70	-296	535	0	5	30	55
91102600	22	17.5N	127.6E	130	12	170	491	836	108	447	505	-131	-205	669	0	5	40	60
91102606	23	17.9N	126.6E	125	6	199	568	905	124	544	577	-156	-165	701	0	15	45	55
91102612	24	18.2N	125.6E	120	11	223	611	912	168	606	-56	-146	85	910	5	20	50	60
91102618	25	18.5N	124.6E	115	8	116	177	156	113	56	-36	-28	168	152	-5	5	30	45
91102700	26	18.5N	123.6E	110	16	118	103	57	106	17	-54	55	102	-21	-10	10	20	35
91102706	27	18.2N	122.8E	105	21	83	59	257	46	-56	-44	70	18	-254	-15	5	15	20
91102712	28	18.0N	122.1E	100	8	58	102	367	13	-69	-104	58	-76	-352	-10	10	30	40
91102718	29	17.8N	121.5E	85	16	57	144	462	-45	-79	-158	36	-121	-435	0	15	35	40
91102800	30	17.8N	121.1E	70	13	113	305	809	-69	59	-70	-90	-300	-807	0	10	20	10
91102806	31	17.9N	120.7E	65	21	154	416	937	-97	104	346	-120	-403	-872	-10	10	15	5
91102812	32	18.1N	120.3E	60	23	163	456		13	31		-163	-455		-5	20	20	
91102818	33	18.5N	120.1E	55	8	53	261		-53	-180		-2	-190		5	30	25	
91102900	34	18.9N	120.0E	50	5	84	372		-38	-146		-76	-343		5	20	10	
91102906	35	19.4N	120.0E	45	5	140	459		-43	39		-134	-458		5	10	5	
91102912	36	19.8N	120.3E	40	5	117			-65			-98			5	5		
91102918	37	20.2N	120.7E	35	13	130			-100			-85			5	0		
91103000	38	20.6N	121.3E	30	30	222			-75			-209			0	0		
91103012	39	21.5N	123.6E	30	28										0			

SUPER TYPHOON RUTH (25W)(CONTINUED)

DTG	WRN NO.	BEST TRACK LAT	BEST TRACK LONG	BEST TRACK WIND	POSITION ERRORS 00	POSITION ERRORS 24	POSITION ERRORS 48	POSITION ERRORS 72	X-TRACK 24	X-TRACK 48	X-TRACK 72	A-TRACK 24	A-TRACK 48	A-TRACK 72	WIND ERRORS 00	WIND ERRORS 24	WIND ERRORS 48	WIND ERRORS 72
91103100	40	23.2N	126.2E	25	26										5			
				Average	16	86	186	306	52	96	148	60	136	238	5	11	22	27
				# Cases	40	38	35	31	38	35	31	38	35	31	40	38	35	31

SUPER TYPHOON SETH (26W)

DTG	WRN NO.	BEST TRACK LAT	BEST TRACK LONG	BEST TRACK WIND	POSITION ERRORS 00	POSITION ERRORS 24	POSITION ERRORS 48	POSITION ERRORS 72	X-TRACK 24	X-TRACK 48	X-TRACK 72	A-TRACK 24	A-TRACK 48	A-TRACK 72	WIND ERRORS 00	WIND ERRORS 24	WIND ERRORS 48	WIND ERRORS 72
91110100	1	8.0N	157.8E	35	61	189	321	403	-86	-170	-268	-169	-273	-301	-10	-10	-25	-45
91110106	2	8.5N	156.6E	40	16	184	306	384	-120	-221	-302	-141	-213	-238	-10	-10	-35	-40
91110112	3	9.3N	155.3E	45	30	164	250	310	-122	-184	-227	-111	-170	-213	-10	-20	-55	-35
91110118	4	10.2N	154.2E	50	11	80	114	129	-44	-95	-121	-67	-63	-45	-10	-15	-50	-20
91110200	5	11.0N	153.0E	55	29	83	102	75	-48	-85	-75	-68	-57	-3	-10	-25	-40	-15
91110206	6	11.9N	151.8E	60	42	72	117	153	-58	-117	-141	-43	4	62	-5	-15	-15	5
91110212	7	12.7N	150.6E	65	38	74	88	164	-70	-88	-141	-23	12	86	-5	-25	0	10
91110218	8	13.4N	149.4E	75	0	45	92	255	-43	-60	-95	17	70	237	-10	-30	5	15
91110300	9	14.1N	148.3E	90	8	49	118	270	-37	-32	-205	33	114	177	-15	0	5	15
91110306	10	14.7N	147.3E	105	13	31	62	251	-24	0	-49	20	62	246	-10	0	10	10
91110312	11	15.3N	146.3E	120	8	51	49	228	29	37	5	-43	33	-228	0	-5	-10	-10
91110318	12	15.9N	145.2E	130	8	50	133	306	50	109	302	12	77	-52	-5	-5	-10	-10
91110400	13	16.4N	144.2E	130	0	17	119	306	-11	-62	303	13	102	-44	0	-5	-5	-10
91110406	14	16.9N	143.2E	130	17	58	111	227	-52	-90	226	27	66	25	0	0	0	-10
91110412	15	17.4N	142.2E	125	0	79	142	225	-68	129	222	41	-61	41	0	-10	-5	-15
91110418	16	17.8N	141.4E	120	0	73	135	287	-34	105	282	65	85	-55	0	-10	-10	-30
91110500	17	18.3N	140.8E	120	0	94	186	364	-73	186	363	60	14	-37	0	-5	-10	-30
91110506	18	18.7N	140.3E	115	13	117	216	393	-67	217	363	96	-7	-152	0	-10	-15	-40
91110512	19	19.1N	140.0E	115	8	107	260	507	34	253	342	-102	-63	-375	0	-10	-15	-45
91110518	20	19.4N	139.7E	110	5	78	224	449	77	210	300	-13	-77	-335	5	5	-10	-40
91110600	21	19.5N	139.5E	105	6	117	346	772	106	331	512	-50	-103	-580	5	-5	-25	-55
91110606	22	19.6N	139.2E	100	11	110	283	606	69	198	309	-87	-203	-522	0	-15	-40	-65
91110612	23	19.6N	139.0E	100	18	135	271	475	98	108	255	-94	-249	-402	-5	-20	-50	-65
91110618	24	19.6N	138.7E	95	20	102	237	482	72	111	298	-73	-210	-380	-5	-25	-55	-65
91110700	25	19.5N	138.2E	95	25	98	218	459	38	85	250	-92	-201	-386	-15	-40	-65	-65
91110706	26	19.4N	137.6E	95	13	56	205	468	53	62	245	-21	-196	-399	-15	-40	-65	-65
91110712	27	19.4N	136.9E	95	8	45	200	468	-18	70	216	-42	-187	-416	-10	-35	-50	-50
91110718	28	19.4N	136.4E	100	8	75	233	445	-5	66	154	-76	-224	-418	-10	-40	-50	-50
91110800	29	19.5N	135.8E	100	8	42	191	410	39	87	147	-18	-171	-383	-5	-25	-25	-25
91110806	30	19.5N	135.2E	105	11	60	174	271	39	50	39	-47	-167	-269	-10	-25	-25	-25
91110812	31	19.4N	134.5E	110	12	95	197	290	62	51	100	-72	-191	-273	-10	-20	-20	-25
91110818	32	19.2N	133.9E	115	12	97	203	318	38	46	148	-90	-198	-282	-15	-20	-25	-20
91110900	33	19.0N	133.2E	115	12	67	121	159	15	10	43	-65	-121	-154	-15	-15	-20	-10
91110906	34	18.7N	132.5E	115	8	29	118	211	2	7	95	-29	-118	-190	0	-5	-5	15
91110912	35	18.5N	131.7E	110	6	29	62	161	-26	-39	-54	-13	-49	-153	5	0	-5	20
91110918	36	18.4N	130.8E	110	0	24	62	208	-23	-60	-106	10	-17	-180	0	-5	0	25
91111000	37	18.3N	130.0E	105	0	33	68	197	10	6	-12	-32	-69	-197	0	-5	5	25
91111006	38	18.2N	129.3E	105	8	24	29	178	25	-8	-47	0	-28	-172	0	-5	15	30
91111012	39	18.1N	128.5E	100	13	36	58	177	36	14	-97	-2	-57	-149	0	-5	20	30
91111018	40	18.0N	127.9E	100	12	18	101	187	18	-11	-187	-6	-101	5	0	5	25	30
91111100	41	17.8N	127.3E	95	13	20	141	170	-12	-90	-151	17	-109	79	5	10	25	30
91111106	42	17.7N	126.8E	95	16	75	207	145	-59	-133	-96	-47	-159	110	-5	15	25	30
91111112	43	17.6N	126.3E	95	12	101	225	95	-51	-171	-95	-88	-148	-9	-5	5	20	15
91111118	44	17.6N	125.7E	85	16	103	191	142	-58	-189	-67	-86	30	-126	0	5	15	10
91111200	45	17.6N	125.1E	75	18	119	141	167	-58	-110	17	-105	89	-167	0	5	5	10
91111206	46	17.8N	124.4E	65	32	146	69		-78	-55		-124	44		0	5	-5	
91111212	47	18.1N	123.6E	60	32	120	29		-103	-10		-62	-27		0	5	0	
91111218	48	18.5N	122.7E	55	21	58	198		-59	42		6	-194		0	0	0	

SUPER TYPHOON SETH (26W)(CONTINUED)

DTG	WRN NO.	BEST TRACK LAT	LONG	WIND	POSITION ERRORS 00	24	48	72	X-TRACK 24	48	72	A-TRACK 24	48	72	WIND ERRORS 00	24	48	72
91111300	49	18.9N	121.9E	50	18	69	249		65	188		23	-164		-5	0	5	
91111306	50	19.3N	121.2E	45	22	120			94			-76			-5	5		
91111312	51	19.5N	120.6E	40	28	166			129			-105			0	5		
91111318	52	19.4N	120.2E	40	30	204			138			-151			0	5		
91111400	53	18.9N	119.9E	35	23	237			132			-197			0	5		
91111406	54	18.2N	119.4E	30	5										0			
91111412	55	17.2N	118.8E	25	11										0			
91111418	56	16.0N	117.7E	25	5										0			
				Average	15	85	163	297	56	99	179	59	111	207	5	12	21	29
				# Cases	56	53	49	45	53	49	45	53	49	45	56	53	49	45

TROPICAL STORM THELMA (27W)

DTG	WRN NO.	BEST TRACK LAT	LONG	WIND	POSITION ERRORS 00	24	48	72	X-TRACK 24	48	72	A-TRACK 24	48	72	WIND ERRORS 00	24	48	72
91110112	1	12.9N	134.0E	30	16	84	181	340	61	151	248	-58	-101	-233	0	10	30	30
91110118	2	13.2N	133.3E	30	43	160	305	516	146	283	358	-66	-116	-372	0	10	25	25
91110200	3	13.3N	132.5E	30	53	194			155			-117			0	0		
91110212	4	13.2N	130.8E	30	48	55			20			-52			0	-5		
91110300	5	13.1N	129.7E	30	12	57			-44			-37			0	-10		
91110312	6	13.0N	128.8E	30	11	115			5			-116			0	-20		
91110400	7	12.7N	127.7E	35	13	96	287	522	56	147	159	-78	-248	-498	0	5	5	0
91110406	8	12.4N	127.1E	40	21	121	343	589	47	132	70	-113	-317	-585	0	10	5	0
91110412	9	12.1N	126.4E	45	0	122	294	500	42	108	-10	-115	-274	-500	0	10	5	5
91110418	10	11.7N	125.6E	45	17	185	418	671	78	93	-28	-168	-408	-671	-5	5	0	0
91110500	11	11.2N	124.7E	40	34	206	453	700	64	82	-33	-196	-446	-700	0	5	0	0
91110506	12	10.8N	123.7E	35	39	213	488	768	5	-40	-176	-213	-487	-748	0	-5	-10	-5
91110512	13	10.4N	122.6E	35	16	188	407	648	-49	-139	-153	-182	-384	-630	0	-5	-5	0
91110518	14	10.2N	121.4E	35	16	143	343		-71	-145		-125	-311		0	-5	-5	
91110600	15	10.3N	120.1E	35	18	114	267		-57	-84		-99	-255		0	0	5	
91110606	16	10.4N	118.7E	35	24	71	195		-52	-51		-49	-188		0	0	10	
91110612	17	10.6N	117.4E	35	88	83	87		17	31		81	-82		0	15	20	
91110618	18	10.8N	116.1E	35	100	94			92			23			0	5		
91110700	19	11.0N	114.8E	35	21	121			84			-89			0	0		
91110706	20	11.1N	113.5E	35	5	81			55			-60			0	0		
91110712	21	11.1N	112.2E	30	47	138			55			127			0	-5		
91110800	22	10.9N	109.4E	30	44										0			
91110812	23	10.4N	106.8E	25	192										5			
				Average	38	126	313	584	59	114	137	103	278	548	0	6	10	7
				# Cases	23	21	13	9	21	13	9	21	13	9	23	21	13	9

TROPICAL STORM VERNE (28W)

DTG	WRN NO.	BEST TRACK LAT	LONG	WIND	POSITION ERRORS 00	24	48	72	X-TRACK 24	48	72	A-TRACK 24	48	72	WIND ERRORS 00	24	48	72
91110518	1	10.1N	161.5E	25	34	125	157	126	-60	-86	-111	-111	-132	-60	5	15	25	35
91110600	2	10.8N	159.9E	25	37	162	199	240	-39	-45	-59	158	195	233	5	15	20	35
91110606	3	11.4N	158.5E	30	35	75	116	203	-34	-42	-32	68	108	201	0	10	20	35
91110612	4	12.0N	157.2E	30	95	142	233	296	-31	-47	84	139	229	284	0	10	15	35
91110618	5	12.7N	156.0E	30	134	144	216	244	1	27	63	-144	215	237	0	5	10	35
91110700	6	13.3N	154.9E	30	18	11	78	199	-11	15	92	-5	77	177	0	-5	0	20
91110706	7	13.9N	153.8E	35	25	130	227	293	96	204	270	88	102	116	-5	0	10	30
91110712	8	14.4N	152.6E	35	32	117	235	348	114	220	321	29	83	135	0	0	15	40
91110718	9	14.9N	151.7E	40	8	42	111	159	36	106	138	22	34	-79	0	5	25	45
91110800	10	15.2N	150.9E	45	52	59	126	213	53	121	176	-28	-37	-121	0	10	30	45
91110806	11	15.6N	150.1E	45	6	5	64	187	3	17	135	-5	-62	-131	0	0	20	45

TROPICAL STORM VERNE (28W)(CONTINUED)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91110812	12	16.0N	149.3E	50	5	17	111	187	8	25	177	-15	-109	-61	0	0	15	30
91110818	13	16.4N	148.6E	55	12	45	107	180	43	53	148	15	-93	-104	0	0	15	30
91110900	14	16.8N	147.9E	55	12	37	106	230	8	61	65	37	-87	-221	0	5	15	35
91110906	15	17.1N	147.3E	55	34	45	157	490	-46	22	51	-4	-156	-488	0	10	20	35
91110912	16	17.4N	146.7E	55	34	91	186	627	-47	126	-1	-79	-137	-627	0	15	25	40
91110918	17	17.9N	146.0E	55	13	89	52		64	31		-63	-43		0	15	25	
91111000	18	18.6N	145.1E	55	13	73	162		18	-66		-71	-149		0	15	30	
91111006	19	19.3N	144.3E	55	11	61	149		61	-86		-6	-123		0	0	10	
91111012	20	20.1N	143.5E	50	30	97	157		45	-142		87	-67		0	-5	0	
91111018	21	21.0N	142.6E	50	50	65			4			-65			0	-5		
91111100	22	22.0N	141.9E	50	16	105			-92			-52			0	0		
91111106	23	23.1N	141.5E	50	43	151			-148			-35			0	0		
91111112	24	24.2N	142.0E	45	36	274			-229			-152			0	5		
91111118	25	25.2N	143.7E	45	76										-5			
91111200	26	26.3N	145.8E	40	60										0			
91111206	27	27.6N	148.4E	40	46										0			
91111212	28	28.8N	151.3E	35	19										5			
				Average	35	90	148	264	53	77	120	61	111	204	1	6	17	36
				# Cases	28	24	20	16	24	20	16	24	20	16	28	24	20	16

TROPICAL STORM WILDA (29W)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91111418	1	10.3N	129.9E	30	50	143			-63			-129			-5	-10		
91111500	2	10.5N	128.7E	35	29	59	75	237	-59	-75	-209	-8	-6	-113	0	0	0	5
91111506	3	10.9N	127.8E	35	24	80	97	178	-55	10	-156	-60	-97	-87	5	15	10	10
91111512	4	11.3N	126.9E	35	21	96	167	226	-59	53	-100	-76	-158	-204	5	15	10	10
91111518	5	11.9N	126.0E	40	5	54	138	222	-32	-32	-187	-44	-134	-121	0	10	10	10
91111600	6	12.7N	125.2E	45	21	21	135	253	-12	-116	-245	-18	-71	66	-5	10	10	10
91111606	7	13.3N	124.2E	45	24	24	112	154	22	-112	-52	11	7	146	5	10	10	20
91111612	8	13.4N	123.0E	45	24	6	116	124	-3	-116	3	-5	-4	125	5	5	10	25
91111618	9	13.5N	121.9E	45	16	123	245	201	123	-242	-22	-3	40	200	5	10	15	35
91111700	10	13.8N	121.0E	45	6	133	221	80	111	-213	-50	-74	64	63	5	15	20	45
91111706	11	14.2N	120.2E	45	18	141	186		136	-91		-38	-163		5	15	30	
91111712	12	15.0N	119.7E	45	11	88	64		-87	-16		-16	62		10	15	35	
91111718	13	15.7N	119.3E	45	13	50	35		-48	31		15	-18		10	10	20	
91111800	14	16.4N	118.8E	45	6	42	199		41	77		-11	-184		10	-5	5	
91111806	15	16.8N	118.4E	45	0	51			-26			-44			5	0		
91111812	16	17.2N	118.0E	45	8	64			-17			-62			5	5		
91111818	17	17.6N	117.5E	45	5	103			53			-89			5	10		
91111900	18	17.9N	116.9E	45	16	155			95			-124			0	10		
91111906	19	17.7N	116.3E	40	8										0			
91111912	20	17.3N	115.7E	35	18										0			
91111918	21	16.7N	114.8E	30	44										5			
91112000	22	16.1N	113.1E	25	8										20			
				Average	17	80	138	186	57	91	113	45	77	125	5	9	14	19
				# Cases	22	18	13	9	18	13	9	18	13	9	22	18	13	9

SUPER TYPHOON YURI (30W)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91112300	1	4.9N	166.4E	30	59	77	114	269	-78	-65	-92	-5	-95	-253	-5	-15	-30	-50
91112306	2	5.2N	166.0E	30	46	36	162	335	-31	1	-19	-19	-162	-335	-5	-15	-30	-45

SUPER TYPHOON YURI (30W)(CONTINUED)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91112312	3	5.5N	165.6E	35	43	72	250	400	-18	-5	-31	-70	-250	-399	0	-10	-30	-40
91112318	4	5.7N	165.1E	40	51	137	320	434	18	38	83	-136	-318	-426	-5	-15	-40	-50
91112400	5	6.0N	164.5E	45	51	203	399	479	36	-2	120	-201	-399	-464	-10	-25	-50	-75
91112406	6	6.3N	163.8E	50	30	179	361	401	37	-2	121	-175	-362	-383	-5	-25	-55	-80
91112412	7	6.5N	162.7E	55	17	147	270	373	7	-21	-3	-147	-270	-373	-5	-35	-55	-70
91112418	8	6.8N	161.3E	65	29	130	226	298	-16	7	-28	-129	-227	-298	-5	-35	-55	-60
91112500	9	7.2N	159.7E	75	13	58	93	186	-14	-13	-135	-57	-93	-129	-5	-15	-15	-15
91112506	10	7.7N	158.1E	85	16	75	109	216	-12	-29	-168	-74	-106	-137	-5	-5	-20	-10
91112512	11	8.2N	156.4E	95	18	71	107	223	7	-45	-150	-71	-98	-166	-5	0	-15	-10
91112518	12	8.7N	154.8E	105	13	47	77	207	38	-43	-137	-30	-65	-157	-10	-20	-30	-20
91112600	13	9.1N	153.1E	115	5	34	79	228	29	-51	-134	-18	-62	-185	-10	-20	-20	-20
91112606	14	9.4N	151.3E	120	13	13	104	241	-13	-101	-190	-2	-24	-148	-10	-25	-15	-15
91112612	15	9.7N	149.6E	125	8	75	161	306	-74	-153	-127	16	-52	-279	-10	-25	-15	-5
91112618	16	10.2N	148.1E	135	5	83	187	350	-81	-157	-96	-19	-102	-338	-10	-20	-10	5
91112700	17	10.8N	146.7E	145	13	60	122	299	-44	-23	-34	-42	-120	-298	-15	0	5	25
91112706	18	11.6N	145.5E	150	8	26	115	363	-25	-86	-108	-8	-78	-347	-5	5	10	30
91112712	19	12.5N	144.0E	150	6	0	82	396	0	-33	-100	0	-76	-383	-5	0	15	30
91112718	20	13.3N	142.7E	150	13	33	120	544	-19	-59	-161	28	-105	-521	-5	0	15	25
91112800	21	14.2N	141.5E	145	17	116	239	523	-108	-189	-279	43	-146	-443	0	0	20	25
91112806	22	15.0N	140.5E	140	8	41	148	394	-40	-58	-38	-12	-137	-393	5	0	15	20
91112812	23	15.9N	139.7E	140	6	59	170	417	-59	-96	-128	-8	-141	-397	5	10	20	25
91112818	24	16.8N	139.2E	135	6	78	274	505	-60	-120	-104	-51	-247	-495	5	20	15	20
91112900	25	17.7N	138.9E	135	8	123	433		-84	-253		-90	-352		-10	-10	0	
91112906	26	18.6N	138.9E	130	5	105	341		-68	-125		-81	-318		-15	-10	0	
91112912	27	19.5N	139.2E	120	8	203	343		-105	-116		-174	-323		-10	-15	-5	
91112918	28	20.4N	139.9E	110	16	179	310		-109	-49		-142	-307		-5	-15	-5	
91113000	29	21.3N	140.9E	105	12	141			-44			-135			-5	-10		
91113006	30	22.4N	142.4E	100	28	201			14			-201			-5	-5		
91113012	31	23.7N	144.4E	95	28	144			94			-110			-5	0		
91113018	32	25.4N	146.9E	90	28	172			172			-11			-5	-5		
91120100	33	27.3N	149.4E	85	42										-10			
91120106	34	29.5N	151.8E	75	52										-5			
91120112	35	31.6N	154.2E	70	53										-5			
91120118	36	33.6N	156.6E	70	20										-5			
				Average	22	97	204	349	48	69	107	72	179	322	7	13	22	32
				# Cases	36	32	28	24	32	28	24	32	28	24	36	32	28	24

TYPHOON ZELDA (31W)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91112718	1	6.9N	173.5E	30	29	50	140	233	-5	-1	-11	-51	-141	-233	-5	-15	-15	0
91112800	2	7.2N	172.7E	35	8	11	90	171	2	-7	-63	-12	-90	-159	-10	-20	-15	0
91112806	3	7.4N	171.8E	40	12	17	82	186	4	-7	-57	-17	-82	-177	-10	-20	-15	10
91112812	4	7.7N	170.8E	45	8	108	199	294	9	8	18	-108	-199	-294	-20	-25	-20	10
91112818	5	8.0N	169.7E	50	34	189	233	289	59	51	113	-180	-228	-266	-25	-30	-20	15
91112900	6	8.2N	168.5E	55	24	161	288	385	29	44	200	-159	-286	-330	-30	20	10	20
91112906	7	8.5N	167.1E	60	5	64	192	445	-33	-54	-7	-56	-185	-446	0	5	15	20
91112912	8	8.9N	165.6E	65	21	89	267	636	-87	-188	-172	-21	-191	-612	0	0	15	25
91112918	9	9.3N	164.0E	70	18	102	305	652	-88	-118	-203	-51	-282	-620	0	10	20	30
91113000	10	9.8N	162.4E	70	13	112	249	528	-28	31	-129	-109	-248	-513	0	10	20	35
91113006	11	10.4N	160.9E	75	26	90	322	591	-22	-60	-147	-88	-317	-573	0	15	20	40
91113012	12	11.2N	159.5E	80	5	125	439	708	-93	-132	-256	-84	-419	-661	0	15	20	25
91113018	13	12.1N	158.1E	80	13	203	515	758	-147	-197	-416	-141	-477	-636	0	20	25	30
91120100	14	13.0N	157.0E	80	5	164	402	468	-78	-150	-310	-145	-374	-351	0	0	5	15
91120106	15	14.1N	156.3E	75	0	172	331	306	-101	-135	-305	-140	-302	-30	0	0	10	15

TYPHOON ZELDA (31W) (CONTINUED)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91120112	16	15.3N	156.2E	75	5	123	245	141	-44	-113	-137	-115	-218	37	0	5	15	15
91120118	17	16.4N	156.6E	70	18	65	145	367	-63	-146	359	-20	-3	75	0	-5	10	20
91120200	18	17.3N	157.3E	70	18	133	228		121	-154		-56	168		-5	0	10	
91120206	19	18.2N	158.3E	70	11	130	337		-32	269		127	203		-10	0	10	
91120212	20	19.0N	159.4E	65	23	118	418		-44	353		110	225		-5	5	10	
91120218	21	19.7N	160.5E	60	50	203	544		-36	539		200	-74		-5	5	15	
91120300	22	20.4N	161.7E	55	6	137			-17			137			-10	0		
91120306	23	21.0N	162.9E	50	30	224			92			205			-5	5		
91120312	24	21.5N	164.0E	45	37	266			188			189			-5	0		
91120318	25	21.9N	164.8E	40	35	262			247			-89			-5	5		
91120400	26	22.3N	165.3E	35	24										-5			
91120406	27	22.8N	165.5E	30	20										0			
91120418	28	23.9N	165.1E	25	66										0			
				Average	20	133	284	421	66	131	170	104	224	353	6	9	15	19
				# Cases	28	25	21	17	25	21	17	25	21	17	28	25	21	17

b. NORTH INDIAN OCEAN

This section includes verification statistics for each warning in the North Indian Ocean during 1991. Pre- and post- warning best track positions are not printed, but are available on floppy diskettes upon request.

JTWC FORECAST TRACK AND INTENSITY ERRORS BY WARNING

TROPICAL CYCLONE 01A

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91011706	1	3.9N	76.1E	30	51	212	248	273	78	34	97	197	246	256	-5	0	15	35
91011712	2	3.7N	75.5E	35	84	210	222		-30	25		208	221		-5	5	20	
91011718	3	3.6N	75.0E	35	144	258	223		-36	79		257	209		0	10	25	
91011800	4	3.6N	74.5E	35	183	307	364		25	133		307	339		5	15	25	
91011806	5	3.6N	74.0E	35	56	45	48		-41	-42		-19	-24		0	10	25	
91011812	6	3.9N	73.3E	35	43	155			-60			-144			0	10		
91011818	7	4.5N	72.3E	35	45	150			-60			-138			0	0		
91011900	8	4.9N	71.2E	35	85	229			-59			-221			0	0		
91011906	9	5.1N	69.8E	30	71	92			24			-90			5	5		
91011912	10	5.1N	68.4E	30	33										0			
91011918	11	5.1N	67.2E	30	38										0			
91012000	12	5.1N	66.0E	30	32										0			
91012006	13	5.3N	65.3E	25	0										0			
			Average		67	184	221	273	45	62	97	175	207	256	2	6	22	35
			# Cases		13	9	5	1	9	5	1	9	5	1	13	9	5	1

TROPICAL CYCLONE 02B

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91042418	1	10.2N	89.1E	35	48	131	120	197	65	-12	-129	-114	-120	-149	-5	0	0	-20
91042500	2	10.7N	88.8E	35	26	18	82	168	18	-82	-168	6	-6	7	-5	-5	-5	-25
91042506	3	11.0N	88.4E	40	42	163	306	348	-123	-242	-348	109	189	-4	-5	0	-10	-45
91042512	4	11.2N	88.0E	40	75	259	333	359	-174	-223	-350	193	248	83	0	5	0	-60
91042518	5	11.3N	87.7E	45	25	119	189	303	-99	-185	-277	66	37	-124	0	5	0	0
91042600	6	11.4N	87.4E	50	21	106	217	422	-105	-198	-293	-18	-89	-305	-5	0	0	-35
91042606	7	11.6N	87.2E	50	29	149	287	511	-135	-147	-335	-65	-247	-387	-5	-10	-5	-45
91042612	8	11.9N	87.3E	55	36	125	267	533	-53	-62	-148	-114	-260	-513	-5	-10	-10	-40
91042618	9	12.2N	87.4E	60	41	136	304	574	-64	-87	-92	-120	-292	-568	-5	-10	-15	-25
91042700	10	12.7N	87.5E	65	60	164	364	683	-53	-68	75	-156	-359	-679	-5	-15	-25	0
91042706	11	13.3N	87.4E	75	11	96	323	722	-15	-121	175	-95	-300	-701	-15	-20	-40	15
91042712	12	13.9N	87.4E	80	33	135	298	609	-134	-189	1	-19	-230	-610	-10	-10	-50	10
91042718	13	14.5N	87.4E	85	23	127	274	601	-105	-136	10	-73	-238	-602	0	-10	-45	40
91042800	14	15.0N	87.6E	90	26	165	409		-71	9		-150	-409		0	-30	-25	
91042806	15	15.6N	87.9E	95	18	99	315		-68	52		-73	-311		-5	-35	5	
91042812	16	16.4N	88.4E	100	8	79	246		10	53		-79	-241		-5	-50	0	
91042818	17	17.3N	88.9E	110	0	58	213		13	43		-57	-209		0	-30	0	
91042900	18	18.3N	89.4E	120	8	88			-20			-86			-5	10		
91042906	19	19.4N	89.9E	130	5	169			-4			-170			0	20		
91042912	20	20.6N	90.7E	140	16	202			-3			-202			0	45		
91042918	21	21.9N	91.6E	135	20	277			-50			-273			0	45		
91043000	22	23.2N	93.0E	110	35										20			
91043006	23	24.2N	94.8E	85	48										25			
91043012	24	25.0N	97.0E	60	54										20			
91043018	25	25.7N	99.7E	40	65										10			
			Average		31	136	267	464	65	112	184	106	222	364	6	17	14	28
			# Cases		25	21	17	13	21	17	13	21	17	13	25	21	17	13

TROPICAL CYCLONE 03B

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91053112	1	16.1N	88.8E	25	29	103	162		-91	-17		-49	-161		0	0	15	
91053118	2	16.9N	89.1E	30	52	73	171		-67	-11		-29	-171		-5	0	20	
91060100	3	17.8N	89.4E	30	29	40	221		-32	-20		-26	-221		0	0	10	
91060106	4	18.7N	89.7E	35	33	126			28			-123			0	10		
91060112	5	19.8N	90.1E	40	17	108			46			-99			0	15		
91060118	6	20.9N	90.5E	45	8	55			28			-48			0	10		
91060200	7	22.1N	91.0E	50	0	132			-21			-131			0	10		
91060206	8	23.5N	91.8E	45	12										0			
91060212	9	24.8N	92.9E	35	28										5			
91060218	10	25.7N	94.5E	30	0										0			
				Average	21	91	184		44	16		72	184		1	6	15	
				# Cases	10	7	3		7	3		7	3		10	7	3	

TROPICAL CYCLONE 04B

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91111406	1	11.1N	81.4E	35	24	21	43		4	-32		21	-30		0	0	15	
91111412	2	11.0N	80.9E	35	76	93	114		-63	-114		69	2		0	0	10	
91111418	3	11.0N	80.3E	40	21	61			-32			-52			-5	5		
91111500	4	11.1N	79.6E	40	29	96			-64			-72			-5	5		
91111506	5	11.4N	78.9E	35	11	61			-48			-38			0	10		
91111512	6	11.7N	78.2E	25	5	34			-13			-32			10	10		
91111518	7	12.0N	77.7E	20	21										15			
91111600	8	12.3N	77.1E	20	108										10			
				Average	37	61	78		37	73		47	16		6	5	13	
				# Cases	8	6	2		6	2		6	2		8	6	2	

c. SOUTHERN HEMISPHERE

This section includes verification statistics for each warning in the South Indian and western South Pacific Oceans from 1 July 1990 to 30 June 1991. Pre- and post- warning best track positions are not printed, but are available on floppy diskettes upon request.

JTWC FORECAST TRACK AND INTENSITY ERRORS BY WARNING

TROPICAL CYCLONE 01S

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
90092100	1	6.5S	71.3E	30	29	131	207		77	151		-107	-142		0	5	5	
90092112	2	7.2S	70.1E	30	16	29	37		17	-4		-25	-37		0	5	5	
90092200	3	7.9S	68.7E	30	0	48	128		-13	-89		-47	-93		0	5	5	
90092212	4	8.5S	66.9E	30	13	78	134		-75	-126		-22	-47		0	5	5	
90092300	5	8.8S	65.4E	30	38	115	200		-92	-180		70	88		0	5	5	
90092312	6	8.5S	63.9E	30	29	42	128		-42	-114		-6	59		0	5	10	
90092400	7	8.6S	61.9E	30	23	36			-36			0			0	5		
90092412	8	8.7S	60.2E	30	16	98			-96			24			0	5		
90092500	9	8.7S	58.7E	30	18										0			
90092512	10	8.7S	57.2E	25	5										0			
				Average	19	72	139		56	110		37	77		0	5	6	
				# Cases	10	8	6		8	6		8	6		10	8	6	

TROPICAL CYCLONE 02S

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
90101806	1	7.0S	71.0E	30	60	218	307		208	77		67	297		0	10	15	
90101818	2	6.8S	70.4E	30	17	48			42			24			0	10		
90101906	3	6.7S	69.8E	25	6	81			59			56			5	5		
90101918	4	6.9S	69.2E	25	30										5			
90102006	5	7.2S	68.5E	20	0										5			
				Average	23	115	307		103	77		49	297		3	8	15	
				# Cases	5	3	1		3	1		3	1		5	3	1	

TROPICAL CYCLONE 03P (SINA)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
90112412	1	10.3S	174.0E	30	17	55	80		-12	81		54	-8		0	0	-40	
90112500	2	11.0S	173.2E	35	41	201	426		199	294		-35	-309		0	-15	-60	
90112512	3	12.1S	173.0E	45	11	111	294		89	93		-67	-279		0	-35	-50	
90112600	4	13.4S	173.0E	65	0	100	318		68	86		-75	-307		0	-40	-20	
90112612	5	15.1S	173.8E	100	0	69	309		41	172		-56	-257		-20	-35	-10	
90112700	6	16.6S	174.8E	125	18	184	415		122	217		-138	-355		-40	-20	5	
90112712	7	18.1S	176.7E	125	0	108	254		84	129		-68	-219		-5	10	25	
90112800	8	18.8S	179.3E	115	8	46			15			-44			-5	15		
				Average	12	109	299		77	153		67	247		9	21	30	
				# Cases	8	8	7		8	7		8	7		8	8	7	

TROPICAL CYCLONE 04S

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
90120300	1	14.2S	78.3E	50	8	155			-73			138			-15	-10		

TROPICAL CYCLONE 04S(CONTINUED)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
90120312	2	15.4S	79.9E	55	29										-10			
90120400	3	16.3S	80.7E	35	49										0			
				Average	29	155			73			138			8	10		
				# Cases	3	1			1			1			3	1		

TROPICAL CYCLONE 05S (LAURENCE)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
90121100	1	13.3S	128.7E	30	18	25			15			20			0	10		
90121112	2	13.8S	128.2E	30	8	72			-61			-40			0	-5		
90121200	3	13.9S	127.6E	35	26										0			
90121212	4	13.2S	126.9E	30	26										-5			
				Average	19	49			38			30			1	8		
				# Cases	4	2			2			2			4	2		

TROPICAL CYCLONE 06P (JOY)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
90121818	1	12.8S	154.9E	30	46	173	186		-140	-131		-103	133		0	5	20	
90121906	2	12.5S	152.7E	30	21	50	157		-19	129		47	91		0	-10	0	
90121918	3	12.3S	151.3E	40	21	42	152		39	134		18	-71		5	10	20	
90122006	4	12.2S	150.2E	50	29	74	146		44	76		-59	-126		0	20	15	
90122018	5	12.9S	149.4E	55	29	122	178		76	151		-96	-95		5	15	-5	
90122118	6	14.6S	147.7E	60	18	77	176		75	172		18	37		0	-10	-40	
90122206	7	15.3S	147.2E	70	8	66	161		6	0		66	-162		-5	-20	-25	
90122218	8	15.8S	146.8E	85	5	61	161		11	40		60	156		0	0	-5	
90122306	9	16.1S	146.6E	90	13	64	175		34	68		54	162		0	-5	-5	
90122318	10	16.3S	146.7E	90	11	64	177		57	136		30	115		0	5	5	
90122406	11	16.6S	146.9E	80	6	53	74		40	2		36	74		0	15	5	
90122418	12	16.9S	147.3E	70	16	65	38		63	18		18	-18		5	15	10	
90122506	13	17.2S	147.7E	55	24	74	82		-74	-67		-10	48		0	0	15	
90122518	14	17.7S	148.0E	45	18	149			-120			-89			0	0		
90122606	15	18.8S	147.5E	45	28	103			-101			25			0	0		
90122618	16	19.5S	146.5E	35	37										0			
				Average	21	82	143		59	87		48	99		1	9	13	
				# Cases	16	15	13		15	13		15	13		16	15	13	

TROPICAL CYCLONE 07S (ALISON)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91011206	1	10.3S	82.8E	25	21	71	164		16	164		70	1		0	5	5	
91011212	2	10.7S	82.7E	25	45	84	208		82	206		-18	-35		0	5	5	
91011218	3	11.0S	82.3E	25	8	42	153		23	152		36	-17		0	0	-5	
91011300	4	11.3S	81.9E	30	18	21	168		18	152		12	-71		0	-5	-10	
91011306	5	11.4S	81.4E	30	11	152	399		153	322		-5	-237		0	5	0	
91011312	6	11.4S	81.2E	30	35	173	416		170	375		-35	-182		0	5	0	
91011318	7	11.5S	81.1E	35	8	132	402		112	317		-72	-249		-5	-5	0	
91011400	8	11.6S	80.9E	45	8	148	396		123	275		-84	-286		-10	-15	0	
91011406	9	11.9S	80.8E	45	18	200	442		95	292		-177	-333		0	-5	0	
91011412	10	12.4S	80.9E	45	32	197	423		129	227		-149	-358		0	-5	5	
91011418	11	12.9S	81.1E	55	29	60	170		57	-167		18	32		-10	-10	-10	
91011500	12	13.4S	81.3E	65	29	56	111		52	-90		-24	-66		-15	0	-5	
91011512	13	15.4S	82.0E	65	11	105	207		-91	-188		-54	-88		0	15	30	

TROPICAL CYCLONE 07S (ALISON)(CONTINUED)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91011600	14	17.4S	82.2E	65	23	112	173		-95	-170		-59	-36		0	10	15	
91011612	15	19.9S	82.1E	60	32	88			-28			-84			5	10		
91011700	16	22.1S	82.0E	50	89	229			-104			204			5	15		
91011712	17	24.2S	82.3E	40	16										0			
91011800	18	26.3S	83.8E	30	44										0			
				Average	26	117	274		84	221		68	142		3	7	6	
				# Cases	18	16	14		16	14		16	14		18	16	14	

TROPICAL CYCLONE 08S (BELLA)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91012000	1	9.9S	81.8E	30	26	262	394		224	244		-137	310		0	10	20	
91012012	2	11.1S	81.9E	30	8	105	70		82	24		-66	67		0	0	5	
91012100	3	12.6S	82.5E	30	46	16	62		14	-57		9	-25		0	0	0	
91012112	4	13.9S	82.6E	30	18	183	321		-114	-244		-143	-210		0	5	5	
91012200	5	14.4S	81.8E	30	54	82	62		1	-61		-82	13		0	0	5	
91012212	6	14.5S	80.7E	30	43	58	72		-56	-68		17	-23		0	5	5	
91012300	7	14.4S	79.7E	35	11	70	162		-8	-37		-70	-158		-5	-5	-5	
91012312	8	14.2S	78.1E	35	36	147	255		-38	-79		-142	-243		-5	-10	0	
91012400	9	14.1S	76.0E	40	8	39	84		11	71		-38	-47		0	5	25	
91012412	10	14.2S	73.7E	45	34	88	74		12	-17		-88	-72		-5	5	10	
91012500	11	14.5S	71.5E	45	69	188	245		-155	193		106	152		-5	-5	-10	
91012512	12	15.0S	69.3E	40	134	330	555		329	163		-32	532		-5	-5	-20	
91012600	13	15.6S	67.6E	40	154	312	412		311	412		-32	14		0	-10	-30	
91012612	14	16.3S	66.9E	40	69	79	219		-69	-205		41	-77		-5	-25	-50	
91012700	15	16.8S	66.5E	45	52	91	232		-17	-229		90	-40		0	-20	-60	
91012712	16	17.2S	65.9E	55	13	132	270		-109	-267		-76	-45		0	-25	-80	
91012800	17	17.4S	65.2E	65	20	124	170		-89	-136		-87	103		0	-45	-90	
91012812	18	17.3S	64.5E	75	18	23	135		2	47		24	-127		0	-45	-55	
91012900	19	17.2S	63.3E	95	13	50	279		40	183		-30	-212		-15	-55	-45	
91012912	20	17.4S	62.2E	120	11	98	328		24	312		-95	-103		10	10	45	
91013000	21	18.0S	61.7E	130	28	211	389		165	381		-131	-82		5	15	50	
91013012	22	18.5S	61.8E	120	34	216	302		198	302		-88	-10		10	35	60	
91013100	23	19.4S	62.9E	110	12	72	141		11	34		-72	-138		5	25	25	
91013112	24	20.9S	63.5E	85	8	48	168		49	98		-2	-137		5	15	5	
91020100	25	22.4S	63.5E	65	8	38	141		-37	-64		-12	-126		0	-5	-10	
91020112	26	23.8S	63.0E	55	27	103	223		-102	-157		-17	-160		0	-5	-10	
91020200	27	25.1S	62.1E	50	21	104	262		-21	-77		-102	-251		-5	-10	-5	
91020212	28	26.9S	61.3E	45	28	156	197		-72	-73		-139	-184		0	-5	0	
91020300	29	29.4S	60.8E	45	31	61			-5			61			0	0		
91020312	30	32.1S	60.7E	40	6	75			5			75			5	5		
91020400	31	34.1S	62.6E	35	7										0			
				Average	34	119	222		79	146		70	129		3	13	25	
				# Cases	31	30	28		30	28		30	28		31	30	28	

TROPICAL CYCLONE 09S (CHRIS)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91021612	1	15.2S	120.8E	30	34	127	150		127	-39		0	146		5	5	0	
91021700	2	15.4S	121.0E	35	26	62	116		-46	-68		-42	-95		0	0	5	
91021712	3	15.6S	121.0E	40	21	67	269		-60	-150		-31	-224		0	0	10	
91021800	4	15.5S	120.6E	45	6	169	285		-17	-138		-168	-250		0	5	20	
91021812	5	15.5S	119.6E	50	21	162	144		-40	-36		-157	-140		0	15	30	
91021900	6	15.7S	116.9E	50	29	53	110		29	-2		45	110		0	5	25	

TROPICAL CYCLONE 09S (CHRIS)(CONTINUED)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91021912	7	15.6S	115.0E	50	39	74	88		74	-81		6	36		-5	15	35	
91022000	8	16.0S	113.4E	50	29	136	227		-53	-200		126	-110		0	25	40	
91022012	9	16.3S	112.3E	40	40	54	93		46	80		-30	48		5	15	15	
91022100	10	16.4S	111.1E	35	5	75	271		-69	89		-30	-257		5	5	5	
91022112	11	16.2S	109.9E	30	0	132			132			7			0	-5		
91022206	12	16.3S	109.4E	30	5	175			-8			-175			0	10		
91022218	13	16.6S	109.5E	30	6										0			
91022312	14	17.0S	111.7E	20	6										0			
				Average	19	98	175		58	88		68	141		1	9	19	
				# Cases	14	12	10		12	10		12	10		14	12	10	

TROPICAL CYCLONE 10S (CYNTHIA)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91021618	1	18.0S	42.2E	35	12	90			76			-48			0	0		
91021706	2	19.1S	43.6E	45	28	94			73			-60			-5	5		
91021718	3	20.5S	44.7E	45	21										-15			
				Average	20	92			75			54			7	3		
				# Cases	3	2			2			2			3	2		

TROPICAL CYCLONE 11S (DAPHNE)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91022200	1	18.5S	122.0E	30	8	73	85		67	84		-32	-17		0	-10	-10	
91022212	2	19.2S	119.8E	35	5	54	126		-38	-39		-39	-120		-5	-20	-10	
91022300	3	19.7S	117.4E	50	5	67	156		-6	-6		-67	-156		0	5	30	
91022312	4	20.4S	114.8E	55	6	168	461		6	-101		-168	451		0	15	20	
91022318	5	20.5S	113.8E	60	24	240	500		-16	-354		-240	354		0	25	20	
91022400	6	20.5S	113.0E	60	28	169	218		-139	4		-97	219		0	20	20	
91022412	7	20.5S	112.2E	50	0	79	45		79	45		12	6		0	5	5	
91022500	8	20.1S	112.3E	40	0	79	281		2	22		-80	-280		0	0	10	
91022512	9	20.6S	112.4E	35	17	109			-19			-108			0	0		
91022600	10	21.7S	111.7E	35	13	173			0			-174			0	10		
91022612	11	23.4S	110.7E	30	40										0			
91022700	12	25.3S	108.7E	25	28										5			
				Average	14	121	234		37	81		101	200		1	11	16	
				# Cases	12	10	8		10	8		10	8		12	10	8	

TROPICAL CYCLONE 12S (DEBRA)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91022406	1	25.1S	35.7E	40	0	105	243		87	54		-60	-238		-5	-30	-50	
91022418	2	25.3S	35.5E	55	17	135	293		-4	-51		-135	-289		0	-5	0	
91022506	3	25.6S	35.9E	65	49	175	325		-52	-244		-168	-215		0	0	0	
91022518	4	25.8S	36.8E	80	26	150	272		90	-116		-121	247		-5	0	5	
91022606	5	25.5S	37.8E	90	26	140	220		48	-154		-132	158		0	0	10	
91022618	6	24.8S	38.6E	90	18	141	228		-125	-202		67	105		0	5	15	
91022706	7	24.2S	38.8E	85	26	127	191		-17	44		-126	-186		5	10	10	
91022718	8	24.4S	38.4E	75	21	124	171		124	171		-5	-4		-5	15	10	
91022806	9	25.1S	38.4E	65	12	12	69		-11	21		-6	-66		5	15	15	
91022818	10	25.7S	38.4E	55	13	39	66		16	-62		36	24		0	-10	-15	
91030106	11	26.3S	38.4E	55	30	26	160		-11	-89		24	-133		0	-5	-15	
91030118	12	27.1S	38.4E	55	23	68	421		-68	-176		-6	-383		-5	-10	-15	

TROPICAL CYCLONE 12S (DEBRA)(CONTINUED)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91030206	13	27.9S	38.0E	50	12	192	701		-48	-278		-186	-644		0	-10	-20	
91030218	14	29.6S	37.5E	50	35	132			-51			-122			-5	-20		
91030306	15	33.2S	37.7E	50	36	386			-212			-324			0	-5		
91030318	16	38.3S	40.4E	50	40										0			
91030406	17	42.9S	46.9E	50	0										0			
				Average	22	130	258		64	127		101	207		2	9	14	
				# Cases	17	15	13		15	13		15	13		17	15	13	

TROPICAL CYCLONE 13P (KELVIN)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91022506	1	15.3S	149.1E	45	16	216	584		-217	363		4	-458		-10	0	15	
91022518	2	16.5S	150.5E	55	11	50	203		5	0		-50	-204		-15	-5	5	
91022606	3	17.3S	150.8E	45	39	278	398		39	106		-276	385		0	10	-5	
91022618	4	17.9S	150.0E	50	16	205	301		-166	-123		-121	275		0	0	0	
91022706	5	15.9S	150.2E	45	8	68	76		64	-75		-24	-12		0	-5	0	
91022718	6	15.5S	150.5E	45	18	86	132		42	62		75	-118		-5	5	0	
91022806	7	15.5S	150.8E	45	11	71	35		70	28		18	-590		0	5	0	
91022818	8	15.5S	150.4E	35	34	23	41		5	-29		24	-30		5	5	0	
91030106	9	15.3S	149.7E	35	53	232	385		232	-382		-22	-54		5	0	-15	
91030118	10	15.0S	150.0E	35	151	313			-313			8			0	-5		
91030206	11	15.3S	150.1E	40	11	79	145		-58	-104		-54	-102		-5	-10	-5	
91030218	12	14.9S	149.8E	40	18	88	141		-52	-98		-72	-102		-5	-10	5	
91030306	13	14.5S	150.2E	45	8	37	108		-29	-75		-24	-78		0	0	5	
91030318	14	14.2S	150.3E	45	34	83	90		58	88		-60	-21		0	10	10	
91030406	15	14.0S	149.9E	45	13	54	150		-6	79		-54	-128		0	10	15	
91030418	16	13.8S	149.5E	35	25	79			54			-58			10	10		
91030506	17	13.4S	149.4E	35	25	86			42			-76			0	5		
91030518	18	13.2S	149.8E	35	48										0			
91030606	19	13.2S	150.7E	30	0										0			
				Average	28	121	199		86	115		58	136		3	6	5	
				# Cases	19	17	14		17	14		17	14		19	17	14	

TROPICAL CYCLONE 14S (ELMA)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91022700	1	13.1S	88.9E	40	11	179	178		-162	-86		-77	-156		-5	-5	25	
91022712	2	14.7S	88.3E	45	18	51	12		45	4		-25	-12		0	5	35	
91022800	3	16.1S	87.8E	60	23	82	122		57	28		-60	-120		5	35	60	
91022812	4	17.6S	88.2E	60	30	38	50		37	42		-10	-28		-5	5	10	
91030100	5	19.0S	88.8E	55	12	84	191		76	175		-37	-78		0	0	-5	
91030112	6	20.2S	89.3E	50	36	118	257		112	199		-39	-164		0	-5	0	
91030200	7	21.4S	90.3E	45	8	60	102		41	-98		44	-30		0	-5	-5	
91030212	8	22.5S	91.0E	45	18	119			103			-61			-5	-5		
91030300	9	23.5S	92.1E	40	8	132			131			-24			0			
91030312	10	25.0S	93.7E	35	29										0			
				Average	19	96	130		85	90		42	84		2	7	20	
				# Cases	10	9	7		9	7		9	7		10	9	7	

TROPICAL CYCLONE 15P

DTG	WRN NO.	BEST TRACK LAT	LONG	WIND	POSITION ERRORS 00	24	48	72	X-TRACK 24	48	72	A-TRACK 24	48	72	WIND ERRORS 00	24	48	72
91030618	1	18.9S	154.0E	30	8										5			
91030706	2	20.1S	153.7E	25	16										10			
				Average	12										8			
				# Cases	2										2			

TROPICAL CYCLONE 16P

DTG	WRN NO.	BEST TRACK LAT	LONG	WIND	POSITION ERRORS 00	24	48	72	X-TRACK 24	48	72	A-TRACK 24	48	72	WIND ERRORS 00	24	48	72
91031800	1	16.0S	163.8E	30	11	61	35		-44	9		-43	-35		0	0	10	
91031812	2	17.4S	164.1E	30	18	86	82		79	-77		-36	-28		0	0	10	
91031900	3	18.9S	164.9E	30	5	54	195		-54	-159		0	-114		5	5	10	
91031912	4	19.9S	165.6E	30	43	373			-309			-209			0	5		
91032000	5	20.2S	164.2E	25	91	293			-109			-273			0	-5		
				Average	34	173	104		119	81		112	59		1	3	10	
				# Cases	5	5	3		5	3		5	3		5	5	3	

TROPICAL CYCLONE 17S (FATIMA)

DTG	WRN NO.	BEST TRACK LAT	LONG	WIND	POSITION ERRORS 00	24	48	72	X-TRACK 24	48	72	A-TRACK 24	48	72	WIND ERRORS 00	24	48	72
91032218	1	7.1S	88.0E	35	18	33	84		-9	22		32	82		0	10	15	
91032306	2	7.7S	87.1E	35	29	60	183		20	78		57	166		10	5	15	
91032318	3	8.3S	86.0E	40	13	73	157		49	122		55	99		5	5	5	
91032406	4	8.9S	85.0E	50	25	41	87		20	76		36	43		0	5	-10	
91032418	5	9.4S	84.0E	50	11	45	114		22	12		-40	-114		0	-5	-20	
91032506	6	10.0S	82.9E	55	5	63	218		63	159		9	-149		-5	-20	-20	
91032518	7	10.7S	81.9E	65	11	89	274		88	268		-18	-57		-5	-20	-10	
91032606	8	11.4S	81.0E	80	31	135	363		129	256		-41	-258		-10	-15	-5	
91032618	9	12.4S	80.3E	90	18	119	337		116	334		-29	-43		-5	0	0	
91032706	10	13.6S	80.2E	90	13	116	143		88	67		-77	127		0	-5	0	
91032718	11	14.8S	80.6E	90	23	32	80		11	-80		30	-2		0	0	0	
91032806	12	15.8S	81.3E	90	18	49	147		-34	-50		36	138		0	0	5	
91032818	13	16.9S	81.9E	85	38	230	518		-160	-516		-167	51		0	-10	-10	
91032906	14	17.9S	81.7E	85	59	263	493		-260	-484		46	96		-5	-10	-15	
91032918	15	18.5S	80.7E	85	24	32	60		22	-2		24	-60		-5	-5	-10	
91033006	16	19.0S	79.9E	80	8	202	660		69	129		-190	-648		-15	-15	-15	
91033018	17	20.1S	79.6E	75	6	192	716		2	-108		-192	-708		-15	-10	0	
91033106	18	22.3S	79.8E	70	26	232			-16			-232			0	5		
91033118	19	25.0S	81.2E	65	37	254			-163			-196			0	10		
91040106	20	28.8S	83.8E	55	7										0			
91040118	21	33.4S	90.0E	45	93										0			
				Average	24	119	272		68	162		78	160		4	8	9	
				# Cases	21	19	17		19	17		19	17		21	19	17	

TROPICAL CYCLONE 18S (ERROL)

DTG	WRN NO.	BEST TRACK LAT	LONG	WIND	POSITION ERRORS 00	24	48	72	X-TRACK 24	48	72	A-TRACK 24	48	72	WIND ERRORS 00	24	48	72
91032500	1	10.5S	99.0E	45	21	171	354		93	347		-144	-69		-10	-65	-45	
91032512	2	10.4S	99.6E	90	11	129	314		17	236		-129	-209		-40	-20	30	
91032518	3	10.5S	99.9E	110	8	138	240		95	139		-102	197		-20	20	55	
91032600	4	10.7S	100.2E	110	13	160	260		106	254		-120	58		-10	25	65	
91032612	5	11.3S	101.0E	110	6	51	248		-18	-134		-48	-209		-5	10	35	
91032700	6	12.2S	101.5E	105	13	83	347		-80	-179		-26	-298		0	20	30	
91032706	7	12.6S	101.7E	100	11	141	422		-95	-161		-106	-390		0	30	35	

TROPICAL CYCLONE 18S (ERROL) (CONTINUED)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91032712	8	13.9S	101.8E	90	54	204	549		-91	-210		-183	-508		0	15	15	
91032718	9	13.3S	101.7E	80	26	235	509		-116	-181		-205	-477		5	15	15	
91032800	10	13.6S	101.2E	70	83	349	611		-159	-195		-312	-580		5	15	10	
91032806	11	13.9S	100.7E	60	25	188	332		31	-20		-186	-332		15	25	25	
91032812	12	14.3S	99.8E	55	84	246			48			-241			0	-10		
91032818	13	14.6S	98.8E	50	55	125			19			-124			0	-5		
91032900	14	15.0S	97.8E	45	11										-10			
91032906	15	15.3S	97.0E	40	11										-5			
91033000	16	16.0S	94.4E	35	75	124			87			-90			5	20		
91033006	17	16.3S	93.6E	35	42	134			54			124			5	5		
91033012	18	16.5S	93.0E	30	35	115			91			71			0	0		
91033100	19	17.0S	91.6E	30	6										0			
				Average	31	162	380		75	186		138	302		7	19	33	
				# Cases	19	16	11		16	11		16	11		19	16	11	

TROPICAL CYCLONE 19S (MARIAN)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91041018	1	10.0S	126.2E	30	13	29	42		6	-24		-29	-36		0	-5	-15	
91041106	2	10.7S	124.8E	35	5	8	58		-3	58		-8	0		0	-15	-15	
91041112	3	11.1S	124.2E	45	6	23	113		22	105		-10	-42		-5	-10	0	
91041200	4	11.7S	122.9E	65	18	41	66		-41	-55		6	-37		10	20	25	
91041212	5	12.5S	121.2E	75	5	138	281		134	53		-35	-276		0	0	5	
91041300	6	13.4S	120.3E	85	0	62	191		-59	133		-19	139		5	5	40	
91041312	7	14.0S	120.1E	90	13	132	200		124	-198		-48	33		0	0	15	
91041400	8	13.9S	119.5E	95	12	141	128		128	-106		61	73		-5	10	15	
91041412	9	13.6S	120.0E	85	5	30	148		-29	-98		-9	-112		0	5	5	
91041500	10	13.9S	120.5E	70	11	134	236		-71	-156		-114	-177		15	15	5	
91041512	11	14.2S	119.5E	60	96	293	446		-36	-194		-292	-403		15	20	10	
91041600	12	14.2S	117.8E	50	0	16	8		5	8		-16	-1		0	-5	-5	
91041612	13	14.6S	116.2E	45	31	126	119		46	110		118	47		0	-5	-5	
91041700	14	15.1S	114.8E	45	6	59	220		59	46		7	-216		0	-5	0	
91041712	15	15.8S	113.6E	40	32	181			99			-152			0	0		
91041800	16	16.7S	112.6E	35	20	142			-34			-138			0	0		
91041812	17	19.1S	111.1E	30	18										0			
91041900	18	22.1S	109.7E	25	35										0			
				Average	18	97	161		56	96		66	113		3	8	11	
				# Cases	18	16	14		16	14		16	14		18	16	14	

TROPICAL CYCLONE 20S (FIFI)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91041600	1	12.4S	102.2E	30	8	5	133		0	18		-6	-132		0	5	-10	
91041612	2	12.5S	102.1E	30	26	90	188		87	105		-24	-156		0	-5	-10	
91041700	3	12.8S	102.1E	35	11	150	305		0	-81		-150	-295		5	0	-10	
91041712	4	14.2S	102.2E	45	8	5	100		5	18		-2	-99		-5	0	-5	
91041800	5	15.7S	102.3E	55	8	74	300		22	35		-71	-298		0	10	10	
91041812	6	17.3S	102.8E	55	0	73	256		4	-71		-74	-246		5	10	0	
91041900	7	19.5S	103.6E	55	0	92			-18			-91			0	-5		
91041912	8	22.3S	105.2E	50	17	39			-34			-19			0	-15		
91042000	9	26.2S	107.1E	45	49	275			-15			275			0	10		
				Average	14	89	214		20	54		79	204		2	7	8	
				# Cases	9	9	6		9	6		9	6		9	9	6	

TROPICAL CYCLONE 21P (LISA)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91050712	1	8.3S	155.0E	30	17	135	158		-136	-139		-12	76		0	-5	0	
91050800	2	9.7S	154.4E	35	36	86	141		76	141		42	-5		0	0	-20	
91050812	3	11.1S	153.9E	45	0	106	184		96	138		-45	-123		0	0	-15	
91050900	4	12.4S	154.2E	55	18	107	222		91	172		-56	-140		0	-5	-10	
91050912	5	13.6S	154.8E	60	12	46	70		26	25		-38	66		5	-5	-5	
91051000	6	14.8S	155.8E	70	11	83	82		82	74		12	37		5	0	5	
91051012	7	16.0S	157.2E	65	24	120	270		30	17		117	270		5	-5	10	
91051100	8	17.0S	159.3E	60	23	83			15			82			5	5		
91051112	9	18.1S	161.7E	50	128	486			35			486			5	10		
91051200	10	18.6S	163.9E	40	21	299			-49			-296			0	-5		
91051212	11	19.3S	167.3E	30	94										0			
				Average	35	155	161		63	100		118	102		2	4	9	
				# Cases	11	10	7		10	7		10	7		11	10	7	

TROPICAL CYCLONE 22S (GRITELLE)

	WRN	BEST TRACK			POSITION ERRORS				X-TRACK			A-TRACK			WIND ERRORS			
DTG	NO.	LAT	LONG	WIND	00	24	48	72	24	48	72	24	48	72	00	24	48	72
91060812	1	10.0S	72.4E	30	6	121	205		10	-3		122	206		0	5	15	
91060900	2	9.9S	71.3E	30	45	129	247		77	15		104	247		5	10	35	
91060912	3	10.0S	70.5E	35	47	108	175		74	171		80	-41		5	25	40	
91061000	4	10.8S	69.3E	40	16	60	171		20	170		57	19		0	15	30	
91061012	5	11.1S	68.6E	35	8	42	143		35	111		24	90		5	20	15	
91061100	6	11.2S	67.7E	35	13	87	200		82	187		30	73		0	0	0	
91061112	7	11.4S	67.1E	35	30	88			88			0			0	5		
91061200	8	11.5S	66.6E	30	31	147			147			13			0	0		
91061212	9	11.5S	66.2E	25	0										5			
				Average	22	98	190		66	109		53	112		2	10	23	
				# Cases	9	8	6		8	6		8	6		9	8	6	

7. TROPICAL CYCLONE SUPPORT SUMMARY

7.1 A TROPICAL CYCLONE WIND SCALE FOR THE TROPICAL PACIFIC

LtCol Charles P. Guard
Joint Typhoon Warning Center, Guam

JTWC has developed a tropical cyclone wind scale for the tropical Pacific fashioned after the Saffir-Simpson Hurricane Scale used in the Atlantic. The scale relates tropical depression, tropical storm, typhoon, and super typhoon wind speeds to potential damage, and indicates the expected effects of coastal waves and surf. The scale considers wind effects on structures and vegetation common to the tropical Pacific region. It also considers the effects of coral reefs on storm surge and wave action. This wind scale is being passed to all tropical cyclone warning centers and to the general public throughout Micronesia, so that the population can better understand the potential impact of the wind speeds it receives in tropical cyclone warnings.

7.2 TROPICAL CYCLONE INTENSITY FORECASTING

Joint Typhoon Warning Center, Guam

Over the last two years, JTWC has placed considerable emphasis on improving tropical cyclone intensity forecasts. The results have been very encouraging. Techniques are based on: (1) the work of Mundell (1990), which relates the potential for rapid or explosive deepening to current intensity at a specific latitude, other location criteria, and month; (2) locally developed rules-of-thumb that consider the relationship of a tropical cyclone to multiple outflow channel mechanisms, such as a combination of mid-latitude troughs, TUTT-cells, and upper-tropospheric channels to the subtropical jet stream; (3) conditional climatology applications that allow specific stratification of current cyclone characteristics to determine the most likely average, maximum, and minimum intensity values at various forecast periods; and, (4) meteorological satellite interpretation of conditions favorable for intensification or weakening, such as vertical shear, TUTT-cell movements, and pixel-counting techniques by Capt Shoemaker as indicated in section 7.12. The Naval Research Laboratory at Monterey, California will adapt the intensity forecast model used in the Atlantic to the Pacific to help JTWC assess its skill.

7.3 HYBRID FORECAST AIDS

Capt Dan B. Mundell, USAF
Joint Typhoon Warning Center, Guam

"Hybrid" forecast aids are defined as a blend of two or more existing forecast aids, and may provide better guidance for the tropical cyclone forecaster than any of the single aids upon which the hybrid is based. Since it is often difficult to determine the "best" aid for each warning, hybrids help reduce the chances for very large errors in difficult forecast situations by weighting the forecast guidance toward the (historically) best-performing aids.

Verification statistics of objective techniques from 1986 to 1991 were used to determine the best- and worst-performing aids in the western North Pacific over a six-year period. A set of regression equations was developed, weighted more heavily toward techniques with the lowest overall forecast errors.

The first hybrid, called BLND, weights nine separate forecast aids (OTCM, CSUM,

FBAM, CLIP, HPAC, TOTL, RECR, CLIM and XTRP) relative to their average errors at 24-, 48- and 72-hours. The second, termed WGTD, is biased toward the dynamic aids OTCM, CSUM and FBAM, which are weighted twice as much as the climatological aids CLIP, HPAC, TOTL and RECR.

7.4 EXTENSION OF CONDITIONAL CLIMATOLOGY DATA BASE

Capt Dan B. Mundell, USAF
Joint Typhoon Warning Center, Guam

The Joint Typhoon Warning Center's conditional climatology data base for the western North Pacific, which is used to identify climatological analogs and derive long-range intensity forecasts, has been updated to include best track positions prior to the issuance of the first warning and extratropical or dissipating cyclone positions after the final warning. This allows JTWC forecasters to pinpoint suitable analogs and determine the most likely rate of intensity change earlier than previously possible.

In addition, best track intensities have been adjusted to agree more closely with dropsonde measurements of minimum sea-level pressure, when available. This adjustment provides greater consistency within the data set because the Atkinson-Holliday (1977) wind and pressure relationship was applied equally as a basis for estimates of maximum sustained winds.

7.5 LATITUDINAL RELATIONSHIP OF TROPICAL CYCLONE PEAK INTENSITY AND PEAKING DAY

Capt Dan B. Mundell, USAF
Joint Typhoon Warning Center, Guam

Two of the most difficult aspects of tropical cyclone intensity forecasting are the peak intensity and the point in time when the anticipated peak intensity will be reached. A high correlation exists between the latitude of initial upgrade to tropical storm and peak intensity in the western North Pacific Ocean (Figure 7-1A), and between the latitude of initial upgrade to typhoon and the peak intensity attained by the cyclone (Figure 7-1B). Generally, low-latitude disturbances, which intensify to tropical storm intensity outside the South China Sea basin, are more likely to become very intense typhoons because they spend a longer time in a favorable low shear and warm sea-surface temperature environment south of the subtropical ridge axis (Figure 7-2).

Application of this latitudinal relationship to future warnings is expected to reduce JTWC's longer range intensity forecast errors (Refer to section 7.2).

7.6 PROTOTYPE AUTOMATIC TROPICAL CYCLONE HANDBOOK (PATCH)

C.R. Sampson, Lt R.A. Jeffries
and Lt S. Aslan
Naval Research Laboratory
Monterey, California

Development of the expert system continues. PATCH is an expert system designed to provide tropical cyclone forecast guidance based on synoptic data, pattern recognition, thumb rules and research results. An automated procedure has been developed to provide guidance for tropical cyclone motion in the western North Pacific. This procedure includes expertise on synoptic patterns, steering, island effects and acceleration after recurvature. In the future, the system will include expertise regarding objective technique performance, tropical cyclone formation, binary interaction and tropical cyclone intensity forecasting.

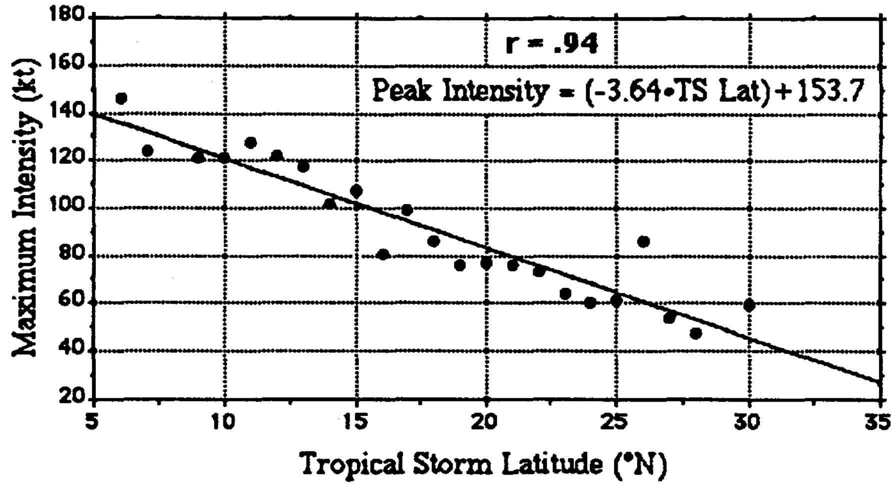

Figure 7-1A

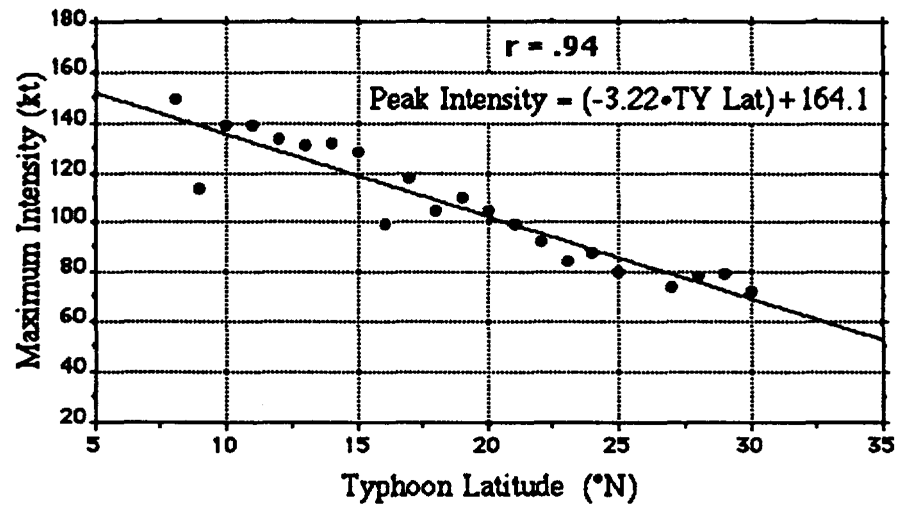

Figure 7-1B

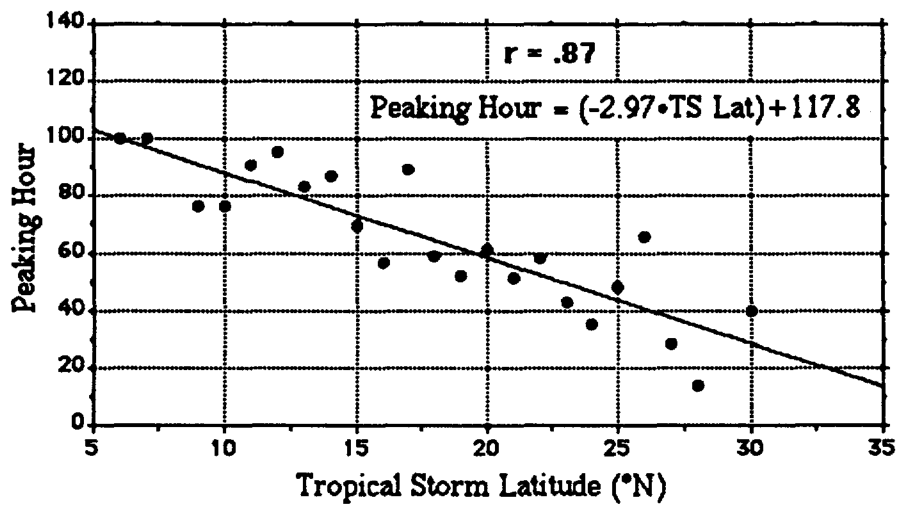

Figure 7-2

7.7 AUTOMATED TROPICAL CYCLONE FORECASTING SYSTEM (ATCF) UPGRADE

D.M. Roesser, R.J. Miller and C.R. Sampson
Naval Research Laboratory (NRL)
Monterey, California

The ATCF has been operational at JTWC since 1988. The system runs on an IBM-AT compatible machine using the MS-DOS operating system. Currently NRL is adapting the ATCF to a UNIX environment. UNIX advantages include multi-tasking, unlimited memory, and portability. The new ATCF will use industry standard X-Windows/Motif for window management.

7.8 JTWC92 MODEL

C.J. Neumann and T.L. Tsui
Naval Research Laboratory
Monterey, California

JTWC92 is a statistical-dynamical model for tropical cyclone track forecasting. It is a modification of the NHC90 model which has shown significant skill in the Atlantic. JTWC92 is currently undergoing operational testing and evaluation and is scheduled to become operational by June 1992. Preliminary results show that forecast errors for 1990 data (125 cases) are 81, 157 and 285 nm for 24, 48, and 72 hours respectively. These results were obtained using operational tropical cyclone positions for model input and best track positions for forecast track verification.

7.9 NEURAL NETWORK APPLIED TO 24-HOUR MOTION FORECAST

J.H. Chu, R.L. Bankert, S.K. Sengupta, P. Rabindra, R.J. Miller, J.M. Shelton and C.R. Sampson
Naval Research Laboratory
Monterey, California

A statistical model for western North Pacific 24-hour tropical cyclone motion forecasts has been developed and tested. The potential predictors of model output are the tropospheric deep-layer-mean height fields and the past 12-hour cyclone motion vectors based on data or derived from data during the period from 1974 to 1989. A feature selection procedure was adopted for ranking these potential predictors according to their significance in discriminating the output classes. Top features based on this ranking are used for training of a probabilistic neural network. The trained neural network model was used to test its forecast ability in 1989. The overall skill score of the statistical model was comparable to that of JTWC forecasts.

7.10 TROPICAL CYCLONE FORECASTER'S REFERENCE GUIDE

Lt R.A. Jeffries, R.J. Miller, J.H. Chu and C.R. Sampson
Naval Research Laboratory
Monterey, California

Development of a Tropical Cyclone Forecaster's Reference Guide continues. The reference guide will contain a section covering general tropical meteorology, formation, motion, structure, and dissipation of tropical cyclones. Satellite and numerical model case studies and descriptions of forecast aids will

also be included. When each section of the reference guide is completed, it is converted to a computer-based information system stored on CD-ROM media.

7.11 NOGAPS TROPICAL CYCLONE FORECAST PERFORMANCE

J.S. Goerss and Lt R.A. Jeffries
Naval Research Laboratory
Monterey, California

Synthetic observations generated from the reported positions and intensities of tropical cyclones have been assimilated into NOGAPS since June 1990. In June 1991, these observations were made available to the 72- and 120-hour forecast runs of NOGAPS as well as to each analysis of the NOGAPS data assimilation cycle. A complete evaluation of NOGAPS tropical cyclone forecast performance in the western North Pacific was performed for 1991.

7.12 TECHNIQUE DEVELOPMENT

Capt Daniel N. Shoemaker, USAF
Detachment 1, 633 Operations Support Squadron

Pixel-counting techniques and insights by Zehr (1987, 1991) are being applied to satellite infrared signatures of tropical cyclones to improve tropical cyclone analysis and forecasting. Although the initial sample (11 tropical cyclones) is small, preliminary thumb rules have been developed and their validity will continue be tested as the data base is expanded.

7.13 ARTICLE FOR *WEATHER AND FORECASTING*

LtCol C.P. Guard, LtCmdr L.E. Carr, F.H.Wells, Lt R.A. Jeffries, LtCmdr N.D. Gural and Lt D.K.Edson
Joint Typhoon Warning Center

The survey article, Joint Typhoon Warning Center and the Challenges of Multibasin Tropical Cyclone Forecasting, was written and submitted to the American Meteorological Society for publication in the Special Military Edition of *Weather and Forecasting*. The paper discusses the challenges to the center as a result of its vast multibasin area of responsibility, the products the center produces, its warning philosophy, observational networks, analysis and forecasting schemes, and the military aspects of the operation. Also briefly discussed are JTWC's colorful history, the joint Navy-Air Force Operations Evaluation to assess the impact of the loss of aircraft reconnaissance, and the ONR's Tropical Cyclone Motion-90 Experiment. Finally, the paper takes a quick look at JTWC's post analysis program, training, qualification, and certification programs; and technique development to improve tropical cyclone analysis and forecasting.

7.14 CHARACTERISTICS OF TROPICAL CYCLONES AFFECTING THE PHILIPPINE ISLANDS

Capt Daniel N. Shoemaker, USAF
Detachment 1, 633 Operations Support Squadron

This study updates two earlier papers, Brand and Blelloch (1972) and Sikora (1976),

on tropical cyclones affecting the Philippine Islands. Forty-five years of data for tropical cyclones near the Philippine Islands were examined to determine tropical cyclone intensity change, track change, occurrence climatology, and various other parameters. From a climatological perspective, the study allows the typhoon forecaster to more accurately anticipate changes in tropical cyclone intensity and motion. This study was published as NOCC/JTWC Technical Note 91-1 and is available from NOCC/JTWC, COMNAVMAR, PSC 489, Box 12, FPO AP 96540-0051.

7.15. TROPICAL CYCLONES AFFECTING GUAM (1671-1990)

Frank H. Wells, Editor
Joint Typhoon Warning Center, Guam

A climatology of tropical cyclones passing near Guam was presented for the period 1945-1990. A review of all typhoons affecting Guam was taken back to 1800, and some noteworthy typhoons of the 1600's were included. The survey encompassed the frequency, behavior, meteorological effects and descriptive chronicles of Guam tropical cyclones. The emphasis was on the period following World War II. This survey was published as NOCC/JTWC Technical Note 91-2 and is available from NOCC/JTWC, COMNAVMAR, PSC 489, Box 12, FPO AP 96540-0051.

7.16 A COST-BENEFIT ANALYSIS OF THE USPACOM TROPICAL CYCLONE WARNING SYSTEM

LtCol Charles P. Guard
Joint Typhoon Warning Center, Guam

A preliminary cost-benefit analysis was conducted with regards to the USPACOM Tropical Cyclone Warning System and indicated annual savings realized from the warning service provided by JTWC to be in excess of $10 million per year. The cost of JTWC support was not presented in the preliminary analysis. These results were presented at the 1992 Annual Tropical Cyclone Conference where the USCINCPAC representative requested that a final study be completed by 1 July 1992 and submitted to Environmental Group USPACOM.

7.17 CONTRIBUTIONS OF THE OFFICE OF NAVAL RESEARCH PhD CHAIR AT THE UNIVERSITY OF GUAM

Dr. Mark A. Lander
University of Guam

In late June of 1991, Dr. Mark A. Lander accepted a newly created Research Associate position at the University of Guam supported by the Office of Naval Research (ONR). His research efforts include new and continuing studies of tropical cyclone motion.

Much of the behavior of tropical cyclone motion can be understood in the context of an interaction of the cyclone with other vortices in the cyclone's environment. When two or more tropical cyclones are within range to interact, the position errors of the forecasts of the JTWC increase. Lander and Holland (1992) extend the work of Dong and Neumann (1983) on the properties of the motion of binary tropical cyclones and develop a generalized model of their specific behavior. Companion papers concerning the theoretical description and numerical simulation of interacting vortices, by Holland with other scientists at the Australian Bureau of Meteorology Research Center, have been submitted along with Lander and Holland (1992) to the *Quarterly Journal of the Royal Meteorological Society*.

In another paper, Holland and Lander (1992), convincing evidence is presented to

show that some of the meandering nature of tropical cyclone tracks can be attributed to interactions between tropical cyclones and mesoscale cloud clusters within the cyclone's outer circulation. This paper has been accepted for publication in the *Journal of the Atmospheric Sciences.*

A close scrutiny of the tropical cyclones occurring in the western North Pacific during 1991 has resulted in a new series of research papers concerning the influence of the monsoon trough on the structure and motion of tropical cyclones. The northward-displaced, self-sustaining, solitary monsoon gyre , the first of a planned series of papers expected to be written concerning the monsoon trough and its affects on the motion and structure of tropical cyclones, is being submitted to *Weather and Forecasting*. The midget tropical cyclone has been written in collaboration with LtCol Guard and is being submitted to *Monthly Weather Review.*

The close proximity of the Joint Typhoon Warning Center (JTWC) to the University of Guam provides a special opportunity to use the assets of the JTWC to monitor tropical cyclones in real time and capture unique and often perishable data on interesting phenomena which are important in research efforts. By virtue of its location in the world's most prolific "Typhoon Alley", Guam (the island itself, the University of Guam, and the JTWC) provides the tropical research meteorologist a unique natural laboratory to study and find answers to existing problems in tropical meteorology.

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APPENDIX A
DEFINITIONS

BEST TRACK - A subjectively smoothed path, versus a precise and very erratic fix-to-fix path, used to represent tropical cyclone movement, and based on an assessment of all available data.

CENTER - The vertical axis or core of a tropical cyclone. Usually determined by cloud vorticity patterns, wind and/or pressure distribution.

EPHEMERIS - Position of a body (satellite) in space as a function of time; used for gridding satellite imagery. Since ephemeris gridding is based solely on the predicted position of the satellite, it is susceptible to errors from vehicle wobble, orbital eccentricity, the oblateness of the Earth, and variation in vehicle speed.

EXPLOSIVE DEEPENING - A decrease in the minimum sea-level pressure of a tropical cyclone of 2.5 mb/hr for at least 12 hours or 5.0 mb/hr for at least six hours (Dunnavan, 1981).

EXTRATROPICAL - A term used in warnings and tropical summaries to indicate that a cyclone has lost its "tropical" characteristics. The term implies both poleward displacement from the tropics and the conversion of the cyclone's primary energy source from the release of latent heat of condensation to baroclinic processes. It is important to note that cyclones can become extratropical and still maintain winds of typhoon or storm force.

EYE - The central area of a tropical cyclone when it is more than half surrounded by wall cloud.

FUJIWHARA EFFECT - A binary interaction where tropical cyclones within about 750 nm (1390 km) of each other begin to rotate about a common midpoint (Brand, 1970; Dong and Neumann, 1983).

INTENSITY - The maximum sustained 1-minute mean surface wind speed, typically within one degree of the center of a tropical cyclone.

MAXIMUM SUSTAINED WIND - The highest surface wind speed averaged over a 1-minute period of time. (Peak gusts over water average 20 to 25 percent higher than sustained winds.)

MONSOON GYRE - A mode of the monsoon circulation characterized by:
1) a large (diameter on the order of 1000 nm (2000 km)) nearly circular low-level cyclonic vortex; 2) nearly circular isobars with the outermost closed isobar possessing a diameter of roughly 1000 nm (2000 km); 3) a northward displacement of the sea-level pressure minimum with respect to the latitude of the pressure minimum found along any meridian passing through the long-term monthly mean monsoon trough; and 4) lower than average sea-level pressure throughout most of the tropical western North Pacific (Lander, 1992).

NORTHWARD-DISPLACED, SELF-SUSTAINING, SOLITARY (NSS) MONSOON GYRE - A specific type of monsoon gyre in the western North Pacific with some particular characteristics:
1) a relatively long (three-week) lifespan; 2) a slow westward migration; 3) a cloud band rimming the southern through eastern periphery of the low-level vortex/surface low; 4) for a least the first half of its lifespan — a subsident regime in its core with light winds and scattered cumulus cloud of little vertical development; and 5) the large circular vortex cannot be the

result of the expanding wind field of a large typhoon (Lander, 1992).

RAPID DEEPENING - A decrease in the minimum sea-level pressure of a tropical cyclone of 1.75 mb/hr or 42 mb for 24-hours (Holliday and Thompson, 1979).

RECURVATURE - The turning of a tropical cyclone from an initial path toward the west and poleward to east and poleward, after moving poleward of the mid-tropospheric subtropical ridge axis.

SIGNIFICANT TROPICAL CYCLONE - A tropical cyclone becomes "significant" with the issuance of the first numbered warning by the responsible warning agency.

SIZE - The areal extent of a tropical cyclone, usually measured radially outward from the center to the outer-most closed isobar.

STRENGTH - The average wind speed of the surrounding low-level wind flow, usually measured within one to three degrees of the center of a tropical cyclone (Weatherford and Gray, 1985).

SUBTROPICAL CYCLONE - A low pressure system that forms over the ocean in the subtropics and has some characteristics of a tropical circulation, but not a central dense overcast. Although of upper cold low or low-level baroclinic origins, the system can transition to a tropical cyclone.

SUPER TYPHOON - A typhoon with maximum sustained 1-minute mean surface winds of 130 kt (67 m/sec) or greater.

TROPICAL CYCLONE - A non-frontal, migratory low-pressure system, usually of synoptic scale, originating over tropical or subtropical waters and having a definite organized circulation.

TROPICAL DEPRESSION - A tropical cyclone with maximum sustained 1-minute mean surface winds of 33 kt (17 m/sec) or less.

TROPICAL DISTURBANCE - A discrete system of apparently organized convection, generally 100 to 300 nm (185 to 555 km) in diameter, originating in the tropics or subtropics, having a non-frontal, migratory character and having maintained its identity for 12- to 24-hours. It may or may not be associated with a detectable perturbation of the low-level wind or pressure field. It is the basic generic designation which, in successive stages of development, may be classified as a tropical depression, tropical storm, typhoon or super typhoon.

TROPICAL STORM - A tropical cyclone with maximum 1-minute mean sustained surface winds in the range of 34 to 63 kt (17 to 32 m/sec), inclusive.

TROPICAL UPPER-TROPOSPHERIC TROUGH (TUTT) - A dominant climatological system and a daily upper-level synoptic feature of the summer season, over the tropical North Atlantic, North Pacific and South Pacific Oceans (Sadler, 1979).

TYPHOON (HURRICANE) - A tropical cyclone with maximum sustained 1-minute mean surface winds of 64 to 129 kt (33 to 66 m/sec). West of 180 degrees east longitude they are called typhoons and east of 180 degrees east longitude hurricanes.

WALL CLOUD - An organized band of deep cumuliform clouds that immediately surrounds the central area of a tropical cyclone. The wall cloud may entirely enclose or partially surround the center.

APPENDIX B

NAMES FOR TROPICAL CYCLONES IN THE WESTERN NORTH PACIFIC AND SOUTH CHINA SEA

Column 1		Column 2		Column 3		Column 4	
ANGELA	*AN-gel-ah*	**ABE**	*ABE*	**AMY**	*A-mee*	**AXEL**	*AX-ell*
BRIAN	*BRY-an*	**BECKY**	*BECK-ee*	**BRENDAN**	*BREN-dan*	**BOBBIE**	*BOB-ee*
COLLEEN	*COL-leen*	**CECIL**	*CEE-cil*	**CAITLIN**	*KATE-lin*	**CHUCK**	*CHUCK*
DAN	*DAN*	**DOT**	*DOT*	**DOUG**	*DUG*	**DEANNA**	*dee-AN-na*
ELSIE	*ELL-see*	**ED**	*ED*	**ELLIE**	*ELL-ee*	**ELI**	*EE-lye*
FORREST	*FOR-rest*	**FLO**	*FLO*	**FRED**	*FRED*	**FAYE**	*FAY*
GAY	*GAY*	**GENE**	*GEEN*	**GLADYS**	*GLAD-iss*	**GARY**	*GAR-ee*
HUNT	*HUNT*	**HATTIE**	*HAT-ee*	**HARRY**	*HAR-ee*	**HELEN**	*HELL-en*
IRMA	*IR-ma*	**IRA**	*EYE-ra*	**IVY**	*EYE-vee*	**IRVING**	*ER-ving*
JACK	*JACK*	**JEANA**	*JEAN-ah*	**JOEL**	*JOLE*	**JANIS**	*JAN-iss*
KORYN	*ko-RIN*	**KYLE**	*KYE-ell*	**KINNA**	*KIN-na*	**KENT**	*KENT*
LEWIS	*LOU-iss*	**LOLA**	*LOW-lah*	**LUKE**	*LUKE*	**LOIS**	*LOW-iss*
MARIAN	*MAH-rian*	**MANNY***	*MAN-ee*	**MELISSA***	*meh-LISS-ah*	**MARK**	*MARK*
NATHAN	*NAY-than*	**NELL**	*NELL*	**NAT**	*NAT*	**NINA**	*NEE-nah*
OFELIA	*oh-FEEL-ya*	**OWEN**	*OH-en*	**ORCHID**	*OR-kid*	**OMAR**	*OH-mar*
PERCY	*PURR-see*	**PAGE**	*PAGE*	**PAT**	*PAT*	**POLLY**	*PA-lee*
ROBYN	*ROB-in*	**RUSS**	*RUSS*	**RUTH**	*RUTH*	**RYAN**	*RYE-an*
STEVE	*STEEV*	**SHARON**	*SHAR-on*	**SETH**	*SETH*	**SIBYL**	*SIB-ill*
TASHA	*TA-sha*	**TIM**	*TIM*	**TERESA***	*teh-REE-sah*	**TED**	*TED*
VERNON	*VER-non*	**VANESSA**	*vah-NES-ah*	**VERNE**	*VERN*	**VAL**	*VAL*
WINONA	*wi-NO-nah*	**WALT**	*WALT*	**WILDA**	*WILL-dah*	**WARD**	*WARD*
YANCY	*YAN-see*	**YUNYA**	*YUNE-yah*	**YURI**	*YOUR-ee*	**YVETTE**	*ee-VET*
ZOLA	*ZO-lah*	**ZEKE**	*ZEEK*	**ZELDA**	*ZELL-dah*	**ZACK**	*ZACK*

* Name changes: MANNY replaced MIKE in 1991; MELISSA replaced MIREILLE, and TERESA replaced THELMA in 1992.

NOTE 1: Names are assigned in rotation and alphabetically. When the last name in Column 4 (ZACK) has been used, the sequence will begin again with the first name in Column 1 (ANGELA).

NOTE 2: Pronunciation guide for names are italicized.

SOURCE: CINCPACINST 3140.1U

APPENDIX C
CONTRACTIONS

A-track	Along-track
AB	Air Base
ABW	Air Base Wing
ABIO	Significant Tropical Weather Advisory for the Indian Ocean
ABPW	Significant Tropical Weather Advisory for the Western Pacific Ocean
ACFT	Aircraft
ADP	Automated Data Processing
AFB	Air Force Base
AFGWC	Air Force Global Weather Central
AFTN	Airfield Fixed Telecommuncation Network
AIREP	Aircraft (Weather) Report
AMOS	Automatic Meteorological Observing Station
AOR	Area of Responsibility
APT	Automatic Picture Transmission
ARGOS	International Service for Drifting Buoys
ATCF	Automated Tropical Cyclone Forecast (System)
AUTODIN	Automated Digital Network
AWDS	Automated Weather Distribution System
AWN	Automated Weather Network
CCWF	Combined Confidence Weighted Forecast
CDO	Central Dense Overcast
CI	Current Intensity
CINCPAC	Commander-in-Chief Pacific (AF - Air Force, FLT - Fleet)
CIV	Civilian
CLD	Cloud
CLIM	Climatology
CLIP or CLIPER	Climatology and Persistence Technique
CM	Centimeter(s)
CNOC	Commander Naval Oceanography Command
CPA	Closest Point of Approach
CPHC	Central Pacific Hurricane Center
CSC	Cloud System Center
CSUM	Colorado State University Model
DDN	Defense Data Network
DEG	Degree(s)
Det	Detachment
DFS	Digital Facsimile System
DMSP	Defense Meteorological Satellite Program
DOD	Department of Defense
DSN	Defense Switched Network
DTG	Date Time Group
FBAM	FNOC Beta Advection Model
FI	Forecast Intensity (Dvorak)
FNOC	Fleet Numerical Oceanography Center
FT	Feet
GMT	Greenwich Mean Time
GOES	Geostationary Operational Environmental Satellite
GTE/PEM-West	Global Tropospheric Experiment/Pacific Exploratory Measurements - West
GTS	Global Telecommun-ications System
HPAC	Mean of XTRP and CLIM Techniques (Half Persistence and Climatology)
HR	Hour(s)
HRPT	High Resolution Picture Transmission
ICAO	International Civil Aviation Organization
INIT	Initial

INST	Instruction
IR	Infrared
JTWC	Joint Typhoon Warning Center
KM	Kilometer(s)
KT	Knot(s)
LAN	Local Area Network
LAT	Latitude
LLCC	Low-Level Circulation Center
LONG	Longitude
LUT	Local User Terminal
LVL	Level
M	Meter(s)
MAX	Maximum
MB	Millibar(s)
MCAS	Marine Corps Air Station
MET	Meteorological
MIDDAS	Meteorological Imagery, Data Display, and Analysis System
MIN	Minimum
MM	Millimeter(s)
MOVG	Moving
MSLP	Minimum Sea-level Pressure
NARDAC	Naval Regional Data Automation Center
NAS	Naval Air Station
NASA	National Aeronautics and Space Administration
NEDN	Naval Environmental Data Network
NEDS	Naval Environmental Display Station
NEPRF	Naval Environmental Prediction Research Facility
NESDIS	National Environmental Satellite, Data, and Information Service
NESN	Naval Environmental Satellite Network
NEXRAD	Next Generation Weather (Doppler) Radar
NHC	National Hurricane Center
NM	Nautical Mile(s)
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NOCC	Naval Oceanography Command Center
NODDES	Naval Environmental Data Network Oceanographic Data Distribution and Expansion System
NODDS	Navy/NOAA Oceanographic Data Distribution System
NOGAPS	Navy Operational Global Atmospheric Prediction System
NR	Number
NRL	Naval Research Laboratory
NRPS or NORAPS	Navy Operational Regional Atmospheric Prediction System
NSDS	Naval Satellite Display System
NSDS-G	Naval Satellite Display System - Geostationary
NSS	Northward-displaced, Self-sustained, Solitary (monsoon gyre)
NTCC	Naval Telecommunications Center
NWOC	Naval Western Oceanography Center
NWS	National Weather Service
OBS	Observations
OLS	Operational Linescan System
ONR	Office of Naval Research
OSS	Operations Support Squadron
OTCM	One-Way (Interactive) Tropical Cyclone Model
PACAF	Pacific Air Force
PACDIGS	Pacific Digital Information Graphics System
PACMEDS	Pacific Meteorological Data System
PACOM	Pacific Command
PCN	Position Code Number

PDN	Public Data Network
PIREP	Pilot Weather Report(s)
RADOB	Radar Observation
RECON	Reconnaissance
RRDB	Reference Roster Data Base
RSDB	Raw Satellite Data Base
SAT	Satellite
SEC	Second
SDHS	Satellite Data Handling System
SFC	Surface
SGDB	Satellite Global Data Base
SLP	Sea-Level Pressure
SSM/I	Special Sensor Microwave/Imager
SST	Sea Surface Temperature
STNRY	Stationary
ST	Subtropical
STR	Subtropical Ridge
STY	Super Typhoon
TAPT	Typhoon Acceleration Prediction Technique
TC	Tropical Cyclone
TCFA	Tropical Cyclone Formation Alert
TCM-90	Tropical Cyclone Motion Field Experiment - 1990
TD	Tropical Depression
TDA	Typhoon Duty Assistant
TDO	Typhoon Duty Officer
TIROS	Television Infrared Observational Satellite
TOGA	Tropical Ocean Global Atmosphere
TOVS	TIROS Operational Vertical Sounder
TS	Tropical Storm
TUTT	Tropical Upper-Tropospheric Trough
TY	Typhoon
TYAN	Typhoon Analog (Program)
TYMNET	Time-Sharing Network: Commercial wide area network connecting micro- and main-frame computers
ULCC	Upper-Level Circulation Center
US	United States
USAF	United States Air Force
USN	United States Navy
VIS	Visual
WESTPAC	Western (North) Pacific
WMO	World Meteorological Organization
WRN or WRNG	Warning(s)
WS	Weather Squadron
X-track	Cross-track
XTRP	Extrapolation
Z	Zulu time (Greenwich Mean Time/Universal Coordinated Time)

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